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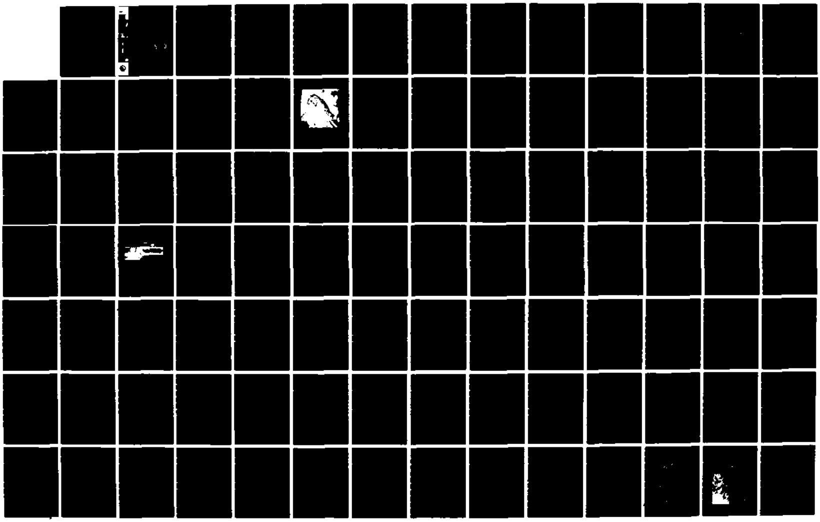

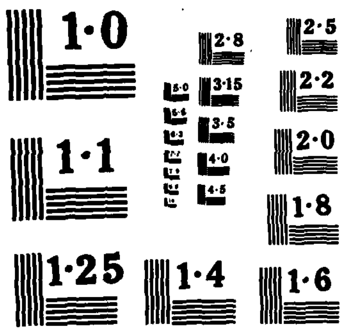

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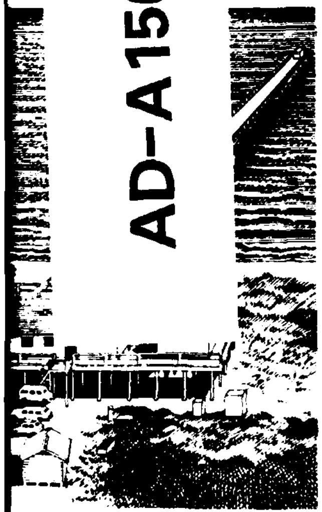

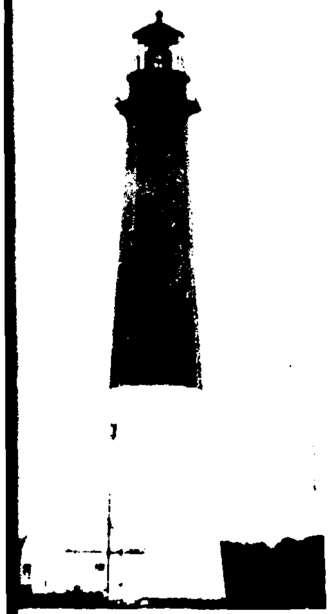

MISCELLANEOUS PAPER CERC-85-1

HISTORY OF EROSION AND EROSION CONTROL EFFORTS AT TYBEE ISLAND, GEORGIA

by

George F. Oertel, Jimmy E. Fowler, Joan Pope

Coastal Engineering Research Center

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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Vicksburg, Mississippi 39180-0631

February 1985
Final Report

Prepared for DEPARTMENT OF THE ARMY
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Under Civil Works Research Work Unit 31232

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The history of erosion and methods of erosion control at Tybee Island, Georgia, is presented. Tybee Island is a barrier island located immediately south of the mouth of the Savannah River. Natural processes and modifications introduced by man have promoted a complex history of shoreline evolution which has important implications for other "developed" barrier islands. Periodic reorientation of the shoreline has caused a history of localized erosion and localized protection efforts. This has resulted in the sequential construction of numerous groins, seawalls, and revetments, in addition to (continued)

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Abstract (Continued)

periodic beach nourishment activities. Each of these efforts is analyzed and presented along with a review of the various engineering and geologic studies which have been conducted over the last 50 years. The current status of erosion and erosion control efforts is presented. Recommendations ~~for the future~~ are also offered. [illegible]

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PREFACE

This report was prepared by the US Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) and is the result of work performed under Civil Works Research Work Unit 31232, "Evaluation of Navigation and Shore Protection." This research is sponsored by the Office, Chief of Engineers (OCE), US Army, and is being conducted at CERC under general supervision of Dr. Robert W. Whalin, Chief.

The report was prepared by Dr. George F. Oertel, Professor, Old Dominion University, Dr. Jimmy E. Fowler, Research Hydraulic Engineer, CERC and Ms. Joan Pope, Research Physical Scientist, CERC. The authors wish to acknowledge the contributions to this report of the following: Dr. J. R. Weggel, former Chief, Evaluation Branch, CERC; Mr. Frank Posey, Civil Engineer, Savannah District; Mr. Darryl D. Bishop, Engineering Technician, CERC; and Mrs. Mary M. Logan, Word Processor, CERC.

Commander and Director of WES upon publication of this report was COL Robert C. Lee, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONTENTS (Concluded)

CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

US customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
degrees (angle)	0.01745	radians
feet	30.48	centimetres
	0.3048	metres
cubic feet	0.02831685	cubic metres
square feet	0.0929304	square metres
inches	25.4	millimetres
	2.54	centimetres
square inches	6.451600	square centimetres
knots	0.5144444	metres per second
miles (US statute)	1.6093	kilometres
square miles	2589.998	square kilometres
millibars	100.0	pascals
yards	0.9144	metres
cubic yards	0.7645549	cubic metres
square yards	0.8361274	square metres

HISTORY OF EROSION AND EROSION CONTROL EFFORTS AT TYBEE ISLAND, GEORGIA

PART I: INTRODUCTION

Purpose

1. The purpose of this report is to compile and organize historical information on erosion and methods of erosion control at Tybee Island, Georgia (Figure 1). The report also provides an evaluation of past and present erosion control endeavors on Tybee Island and presents recommendations based on this evaluation. The historical experience on Tybee Island may assist in the coastal planning for Tybee and other similarly developed barrier islands.

Background and Setting

2. Tybee Island is a barrier island on the coast of Georgia between the Savannah River and Tybee Creek. It is one of four islands that form the subaerial outer edge of the Savannah River delta. The island has 3.5 miles* of shoreline along the Atlantic Ocean and an average summer population of about 12,000 (25,000 on summer holidays). The Savannah River basin drains 17,020 square miles; Tybee Creek has a drainage basin of less than 1.2 square miles in a marsh-lagoonal area. Tybee Creek probably was a distributary of the Savannah River delta during an earlier stage of this river-delta system (Figure 2).

3. The shores of barrier islands are dynamic areas that undergo constant change in response to numerous natural and man-induced processes. The historical documentation of such change can vary considerably for different locations. The earliest records on Georgia's barrier islands are maps and charts prepared during the late 1700's and early 1800's. Although the accuracy of these early records is suspect, advances in technology during ensuing decades have yielded considerably more reliable documentation of

*A table of factors for converting US customary units of measurement to metric (SI units) is presented on page 4.

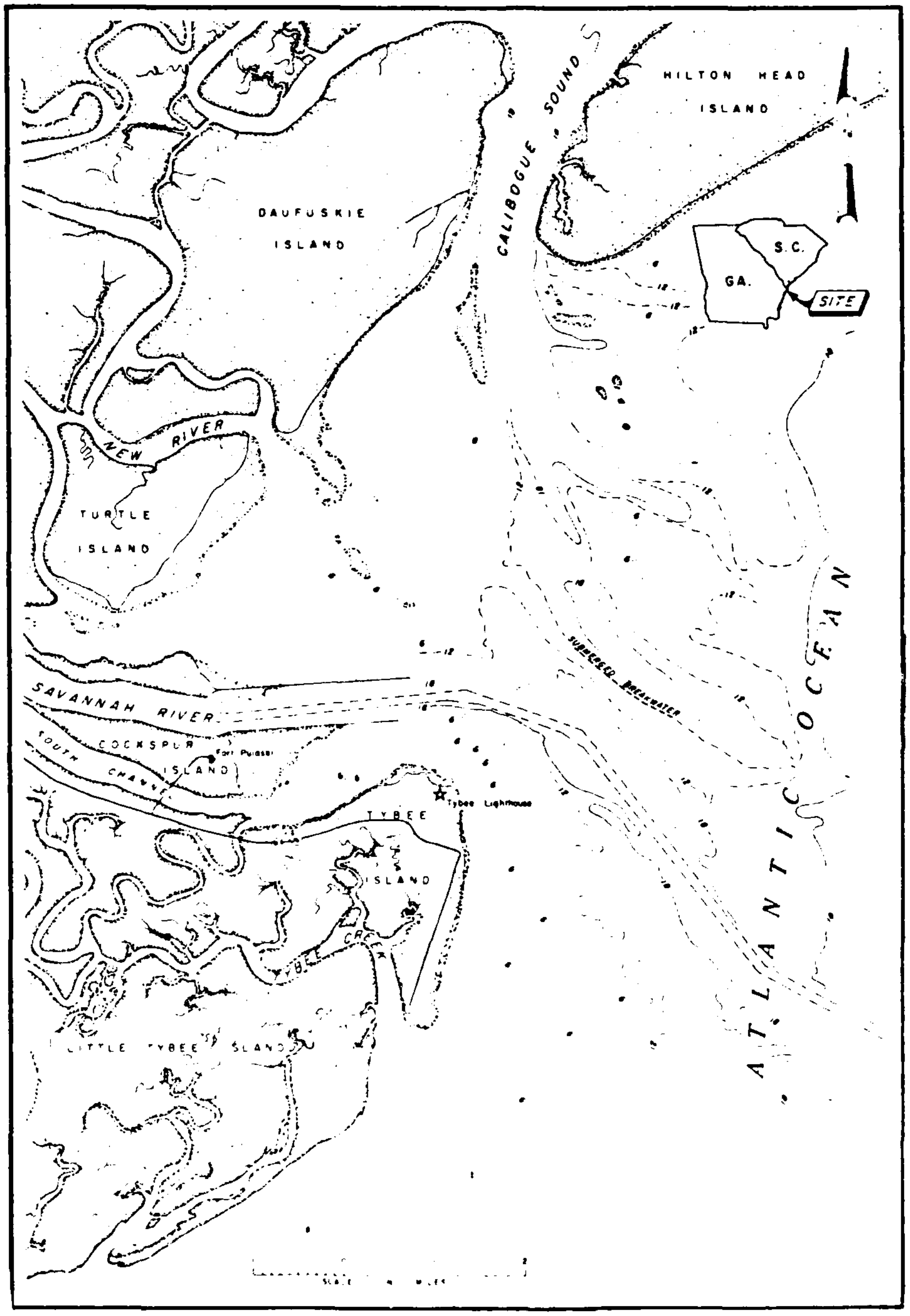


Figure 1. Vicinity and location map

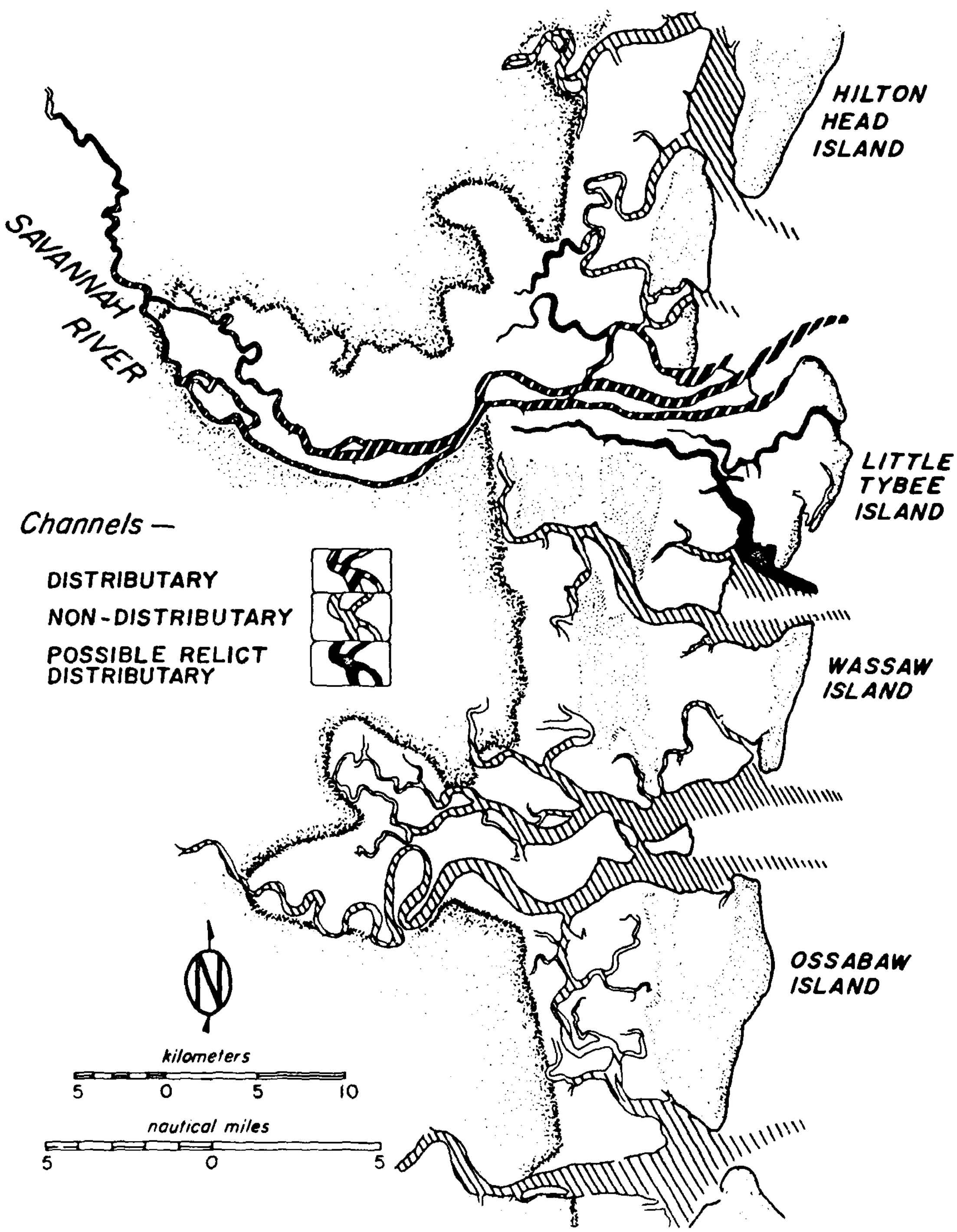


Figure 2. Relict distributaries of the Savannah River and nondistributary channels (Oertel 1979a)

shoreline changes. The most accurate estimates have been made since the late 1930's using aerial photographs and more sophisticated surveying techniques.

Factors Affecting Erosion and Accretion Rates

4. Patterns of erosion and accretion on the shores of barrier islands are primarily caused by the transfer of wave energy to the loosely packed material composing the shore. Non-wave induced currents (such as tidal currents) have a smaller impact on the shore but are important in determining the sediment budget of the shoreface below mean low water (MLW). Since wave energy dissipation is a major factor influencing erosion at Tybee Island, it is important to understand the wave climate of the area. Appendix A presents a summary of wave data in the Tybee Island area as obtained from the Corps of Engineers Sea-State Engineering Analysis (SEAS) (Ragsdale 1983).

5. Wind waves approaching Tybee Island are caused by two seasonally distinct climatic conditions (Nummedal, et al., 1977, Oertel and Howard 1972). During spring and summer months, high pressure systems (called "Bermuda highs") generally exist offshore between 65° W and 75° W longitude and 27° N and 37° N latitude. The clockwise rotation of air in these systems produces mild winds from the south that propagate low-energy waves onto Tybee Island. These waves transport littoral material from south to north during much of the period between early spring and mid-fall (Oertel 1974). Since this is a relatively low-energy process, there is little evidence of erosional truncation (or scarping) of the upper part of the beach during these seasons.

6. The major climatic events of the fall and winter are related to strong low pressure systems, including hurricanes. The counterclockwise flow of air in these systems produces strong winds from the north that drive high energy waves onto the shore, causing north to south longshore transport over several days. These conditions often result in severe and rapid erosion of the shore. This rapid erosion often causes truncation or "scarping" of the upper foreshore and backshore. While these events are generally only a few days in duration, they produce significant shifts in shoreline position and beach elevation. The northeast part of Tybee Island more directly feels the effect of these storm waves. Prior to construction of a concrete bulkhead in 1941, material eroded from the northeast was transported alongshore in both northwesterly and southwesterly directions. Subsequent deposition of this

protection and groins for beach building purposes." This was the basis for the projects WP-6347 and WP-7051 which were intended to "close the gaps in the general protective scheme for the entire island and to give continuous structural protection from south end of the inlet to the north end on that section known as the Fort Screven Reservation." The proposed projects were also supported by the thesis that the continuous structure would prevent flanking actions on the northern and southern projects.

22. In December of 1940, the District Director of the WPA proposed that the section of bulkhead between Third and Center Streets be modified to straighten a 90-deg offset that resulted from the original construction. Construction of a section of concrete bulkhead on a diagonal between Third and Center Streets was authorized by WP-6347, and the proposed modifications were made accordingly.

23. A reinforced concrete bulkhead extended from First Street to Tybee Creek at the southern end of Tybee Island, and sixteen additional timber groins were also completed by late 1941. The dimensions of the bulkhead varied at different sections of the shore. The elevation of the cap was approximately 12.0 ft above MLW, and metal tie rods were anchored into deadmen behind the seawall to provide additional support.

Measures Employed Between 1942 and 1970

24. The town of Savannah Beach (now the city of Tybee Island) purchased the Coast Artillery Base (i.e. Fort Screven), thus incorporating the entire ocean shoreline of Tybee Island in 1946. In June 1955, the 85th Congress authorized a hurricane survey of Tybee Island which resulted in a report and accompanying papers (Secretary of the Army 1960). The report indicated that no economically justifiable method was available for protecting Tybee Island from severe hurricane damage and that the existing concrete bulkhead was adequate protection from moderate hurricane waves. The report recommended that no further improvements for hurricane protection on Tybee Island be undertaken by the United States Government at that time.

25. Storm waves of Hurricane Dora (1964) caused the northernmost section of seawall to fail. The Federal Office of Emergency Planning (OEP) authorized construction of rock protection that extended approximately 5,000 ft along the beach north of Center Street. The riprap protection fronted the 1941 section

Construction was initiated in the spring of 1936 and completed in 1938. The bulkhead elevation was +12.0 ft MLW and the groins sloped from +10.0 ft MLW at the landward end to approximately +2.5 ft MLW at the seaward end. The five groins were established in an effort to trap and hold longshore drift, but it is doubtful that quantitative or even qualitative studies were used to establish the patterns or rates of sediment dispersion along the shore.

<u>1939-1941</u>

19. Between 1939 and 1941, WPA projects WP-5139, W̄-6347, and WP-7051 were completed to protect the shore from the southern end of Fort Screven to the southern tip of the island at Tybee Creek (microfilm from Savannah District 1939, 1940, 1941). The design of these projects was modified several times between inception and construction. The initial project was a continuation of the 1931-1933 WPA project. Design specifications in May 1939 included construction of 600 lin ft of concrete bulkhead, 2,000 lin ft of timber groins, and 25,000 cu yd of sand fill to be placed behind the bulkhead. At this time, two areas of the Tybee Island shore required additional protective measures (Figure 9c). The section at the southern end of the island from Seventeenth Street to Tybee Creek was chosen for the initial work. Later, a section at the middle of the island between Tilton and Second Streets was built. Temporary timber bulkheads were constructed to allow permanent concrete bulkhead construction and deposition of backfill. Concurrent with bulkhead installation, seven permanent timber groins were constructed.

20. The May 1939 design was modified in December 1939 to change the wood bulkhead at the center section of the beach to a concrete bulkhead and to extend it between Second and Fourteenth streets, a distance of approximately 6,100 ft. Another modification called for construction of five timber groins in Tybee Creek Inlet (Figure 9c). The groins were designed to trap sediment and influence the tidal current pattern. Following construction of the bulkhead, 57,000 cu yd of fill were placed. Of this total, it is estimated that approximately 15,000 cu yd were eroded from the beach within two years.

21. In early 1940, a statement of the success of the concrete bulkhead and groin projects between First and Second Streets and at the southern end of the island was prepared (microfilm from Savannah District 1940). In this report, it was stated that "...the most effective method of protection is by means of a combination of bulkheads and groins; bulkheads for shoreline

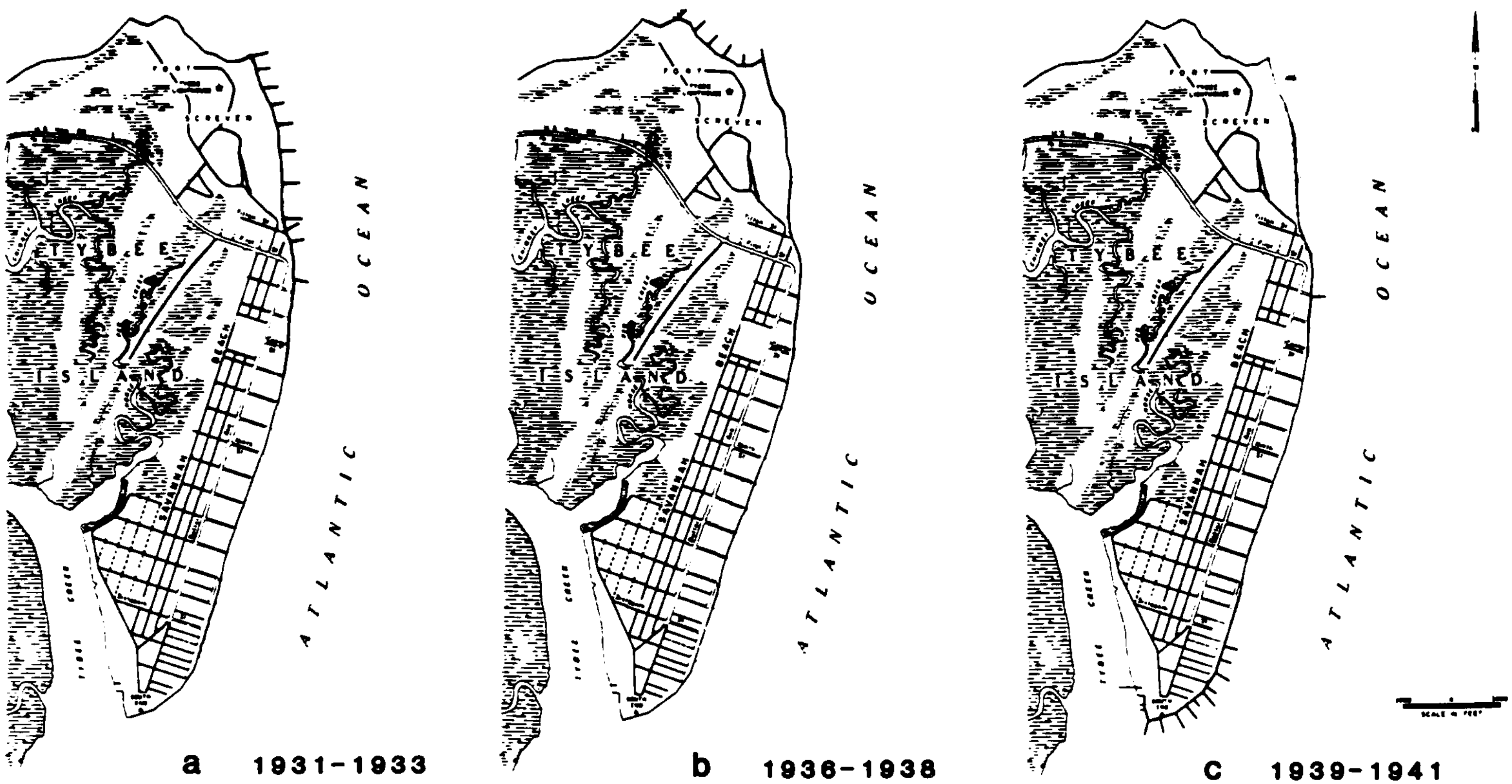


Figure 9. Locations of 1931-1933, 1936-1938, and 1939-1941 WPA shore protection efforts (Office, Chief of Engineers 1981)

Works Projects Administration Efforts

1931-1933

16. Another erosion control project was initiated in January 1931. The improvements extended north approximately 2,650 ft from the southern boundary of Fort Screven. The project was authorized by the Works Projects Administration (WPA) and consisted of a 2,650-ft-long bulkhead and five groins extending from the new bulkhead seaward to the "Old Sea Wall" (Figure 9a). Design standards for the 1931 Fort Screven bulkhead and groins were described in the War Department Appropriation Act, 1930. The south end of the bulkhead was protected from wave action by 1,000 tons of rubble stone. No mention was made of protection for the northern end of the bulkhead. The top of the bulkhead was constructed to 13 ft above MLW. The groins sloped from +12 ft MLW at their landward end to +2 ft MLW at the offshore end. The bulkhead and groins were constructed of interlocking steel sheetpile with a minimum 3/8-in. wall thickness.

17. Approximately 100 lin ft of the 1931 bulkhead had failed by 1933 and the brace pile connections were deteriorating along the old bulkhead and groins. In April 1933, plans were approved to:

a. Restore the section of bulkhead that had failed.

b. Reinforce connections in the bulkhead and groins.

c. Construct an additional 1,325 lin ft of bulkhead.

d. Build three new groins along the new section of bulkhead.

e. Place 1,400 tons of riprap on a log mattress.

The design of the new work was almost identical to the 1931 effort except that the connections of brace piles were made stronger. Completion of this plan was delayed by a lack of funds, and in 1934 a new set of recommendations for erosion control was made by the Beach Erosion Board (BEB) to the Chief of Engineers.

1936-1938

18. Conditions adjacent to Fort Screven changed sufficiently from 1933 to 1936 to warrant a new study and recommendations for immediate actions. The 1936-1938 effort to control erosion at the extreme northern end of Fort Screven (Figure 9b) was significantly different than the 1931-1933 plan. The plan resulted in construction of approximately 2,000 lin ft of bulkhead and five groins that extended toward the Savannah River, all of creosoted wood.

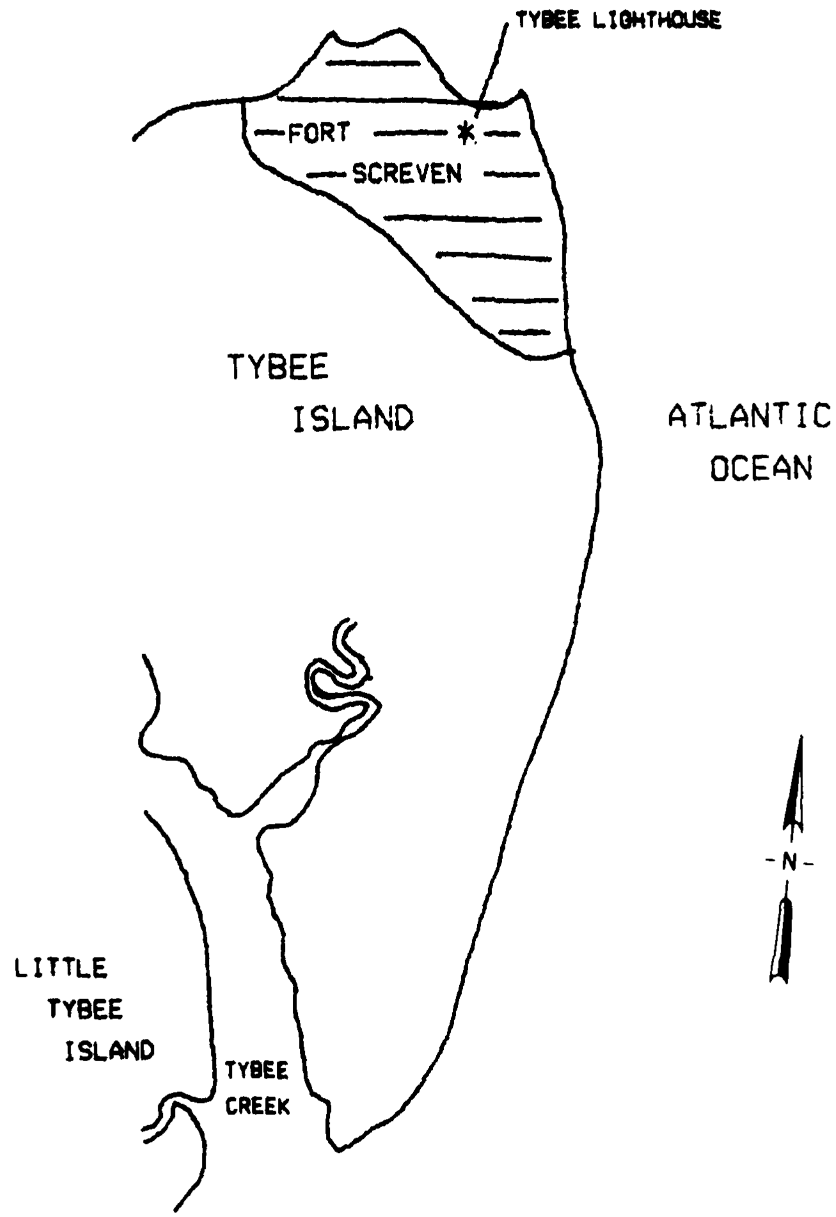


Figure 8. Location of Fort Screven

PART II: HISTORY OF EROSION CONTROL MEASURES AND STRUCTURES

Measures Employed Prior to 1930

14. Three rock groins were constructed at the north end of the island in 1882 (US Army Engineer District, Savannah 1970). It is not known whether this initial effort was specifically designed to control erosion or if it was related to the training jetty program for navigational improvements to the Savannah River. In that program numerous training jetties were established along the margin of the Savannah River to alter natural currents (to control erosion and accretion patterns) and enhance navigation. A National Coast Survey chart dated 1918 (Appendix C) shows the location of ten groins along the shore of the northern one-third of Tybee Island. Six of these structures were constructed of wood and four were of rock. The groins on the north end of Tybee Island were oriented perpendicular to the axis of the Savannah River channel. Speculation on other characteristics of groin design beyond orientation is difficult due to structural settlement and deterioration that has taken place over nearly a century. Five wooden groins located at the southern tip of Tybee Island were also shown on the 1918 National Coast Survey chart.

15. The Fort Screven Coast Artillery Base was established on Tybee Island in 1897 (Figure 8). Protection of Base property from shore erosion was to become a major concern by the 1930's. While records of erosion control projects prior to 1930 are lacking, at least two other significant undertakings were accomplished in the period 1912 to 1930. A report by CAPT R. F. Gill (1931) illustrated an old structure called the "Tybee City Groyne" that was apparently located between Tilton Street and the present position of First Street. The report also notes another structure termed the "Old Seawall," which extended from the north end of the island southward for approximately 6,000 ft to First Street. This structure is probably the seawall constructed in 1912 by the US Army. The Tybee City Groyne referred to by Gill is probably a part of what is elsewhere referred to as the Central Beach Protection Works, built during 1928 and 1929. The 1931 National Coast Survey chart also shows three wooden groins which were part of the Central Beach Protection Works. These three wooden groins were located between Tilton and Third Streets.

erosion of the nourishment material. From April 1976 to August 1978, approximately 62 percent of the sand placed along the southern 2,100 ft of the project had been lost. This erosion problem prompted studies by the Savannah District and others (Oertel 1978a, Posey and Seyle 1980).

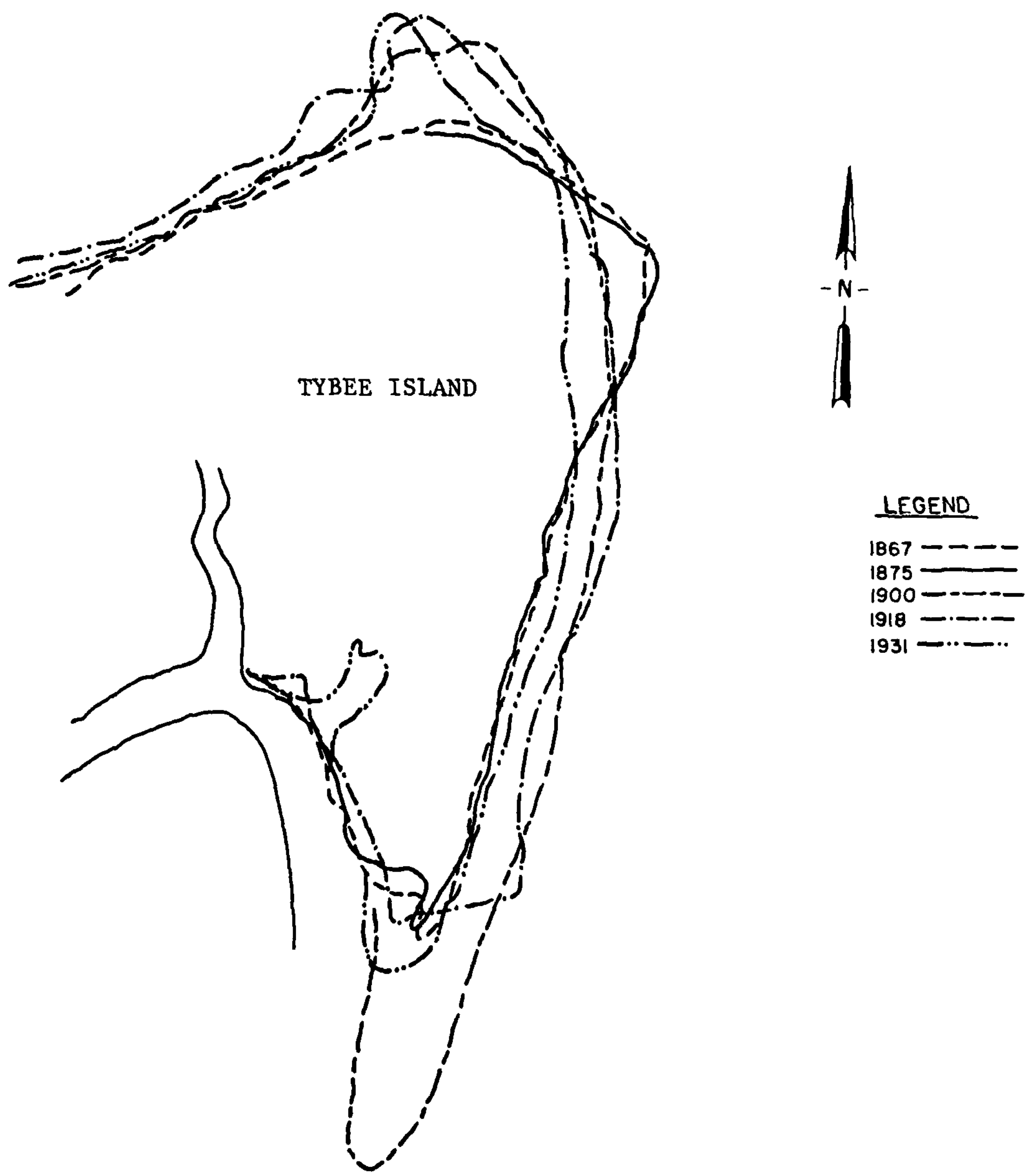


Figure 7. Tybee Island MHW shoreline positions for various years

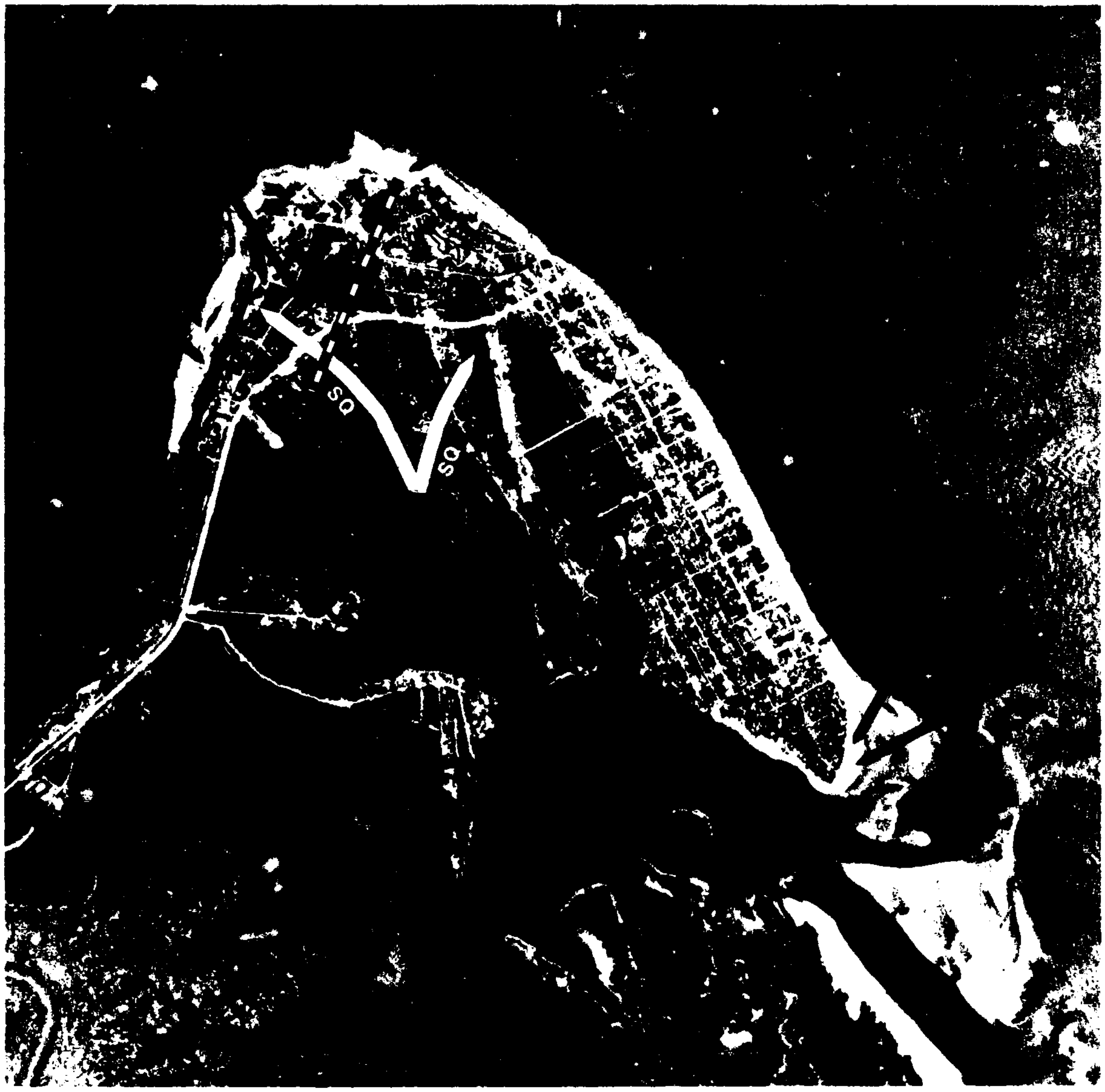


Figure 6. Aerial photograph of Tybee Island (1978). The T shows the approximate position of the beach ridge truncation during the Holocene time period. The white arrows (SQ) show the directions of sequential beach-ridge development. Beach ridges A-F represent the late Holocene development of Tybee Island in a west and northwest direction. Ridges S1, S2, S3, and S4 are relatively recent dune ridges that illustrate modern accretionary trends of the island

History of Erosion

11. Prior to 1854, the shore of Tybee Island was apparently characterized by significant periods of accretion, as illustrated by the sequential and seaward development of beach ridges (Figure 6). The regularly spaced dune ridges on the southern (Tybee Creek) end of the island suggest that accretion was continuous. Development of the north end of the island has been much more irregular, as indicated by the truncations between beach ridge sets.

12. Since 1854, the northeastern portion of the island has eroded at moderate rate to rapid rates, the eastern portion has remained relatively stable, and the northwestern and southeastern portions have experienced significant accretion (Figure 3). Erosion problems initiated a program in 1855 to develop a series of charts of the Tybee Island area (Appendix C). Figure 7, which was prepared from several of these charts, depicts the shoreline position on Tybee Island over a 65-year period. The northern portion of Tybee Island, near the lighthouse, apparently migrated in a northwest direction between 1900 and 1931. As indicated by Figure 7, Tybee Island apparently has experienced two periods of high recession rates from 1875 to 1900 and from 1918 to 1931. Maximum rates of shoreline recession in this area (from 1896 to 1916) have been estimated to be 35 ft per year (Oertel and Chamberlain 1975). The majority of this rapid shoreline recession most likely resulted from several hurricanes (Table 1) which passed very close to Tybee Island. After 1916, the average shoreline recession rate decreased to 7 ft per year and continued at this rate until the late 1930's. Posey and Seyle (1980) indicate that the northern 5,800 ft of Tybee Island experienced a shoreline recession of 6.7 ft per year between 1920 and 1972. The middle 3,200 ft of Tybee Island experienced periods of accretion and recession with little net change during the period 1854 to 1975. The southern end of Tybee Island accreted at a rate of approximately 20 to 25 ft per year from 1897 to 1975. Appendix E contains a series of photographs which illustrate shoreline conditions at Tybee Island.

13. During the late 1960's and early 1970's erosion along the island prompted the Savannah District to nourish the beach with 2.262 million cu yd of sand which added an additional 3,254,000 sq ft of beach to the total area above MLW. Soon after, the southern tip of the island experienced accelerated

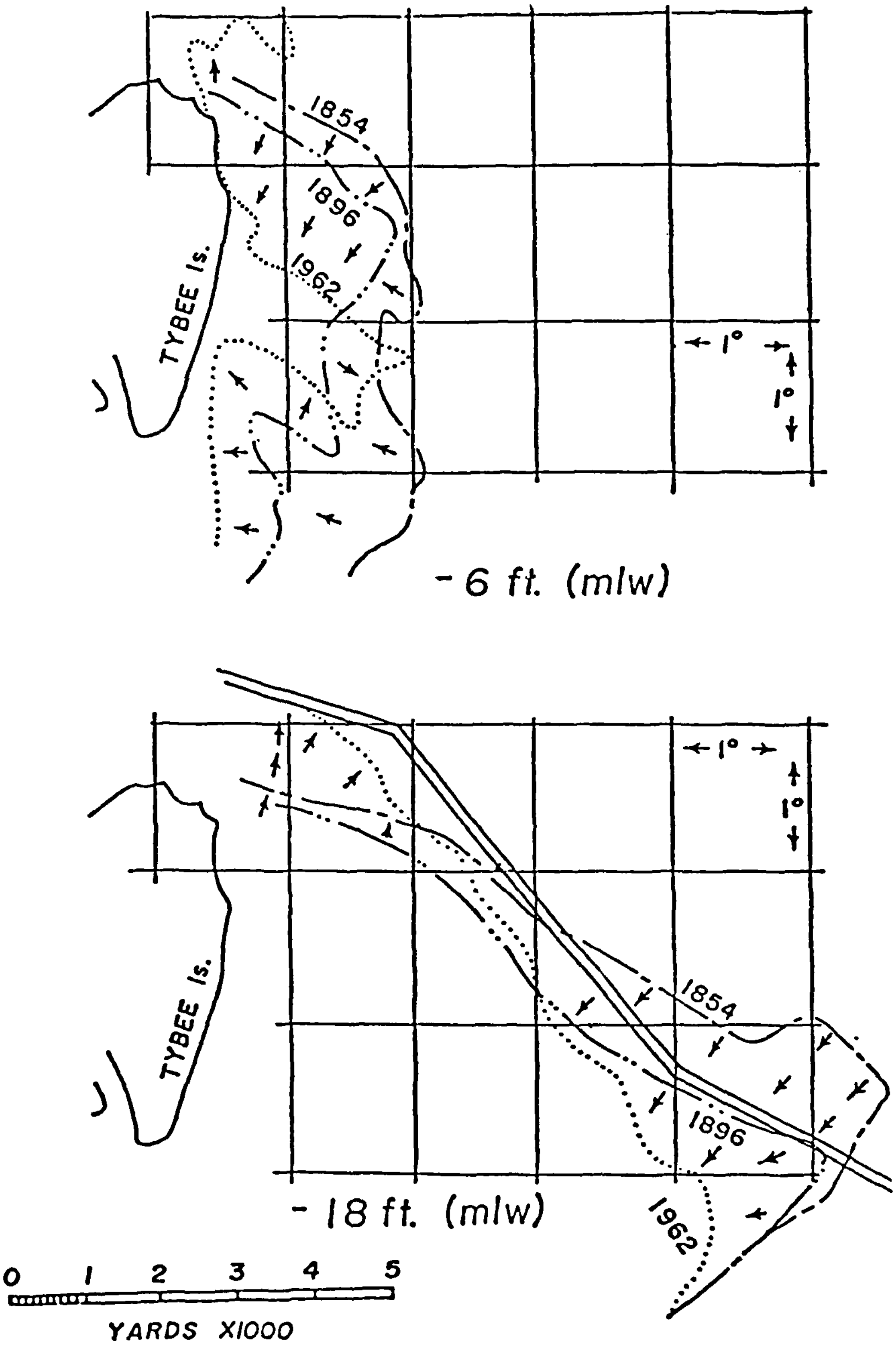


Figure 5. Changes in the subaqueous platform adjacent to Tybee Island (Oertel 1978a)

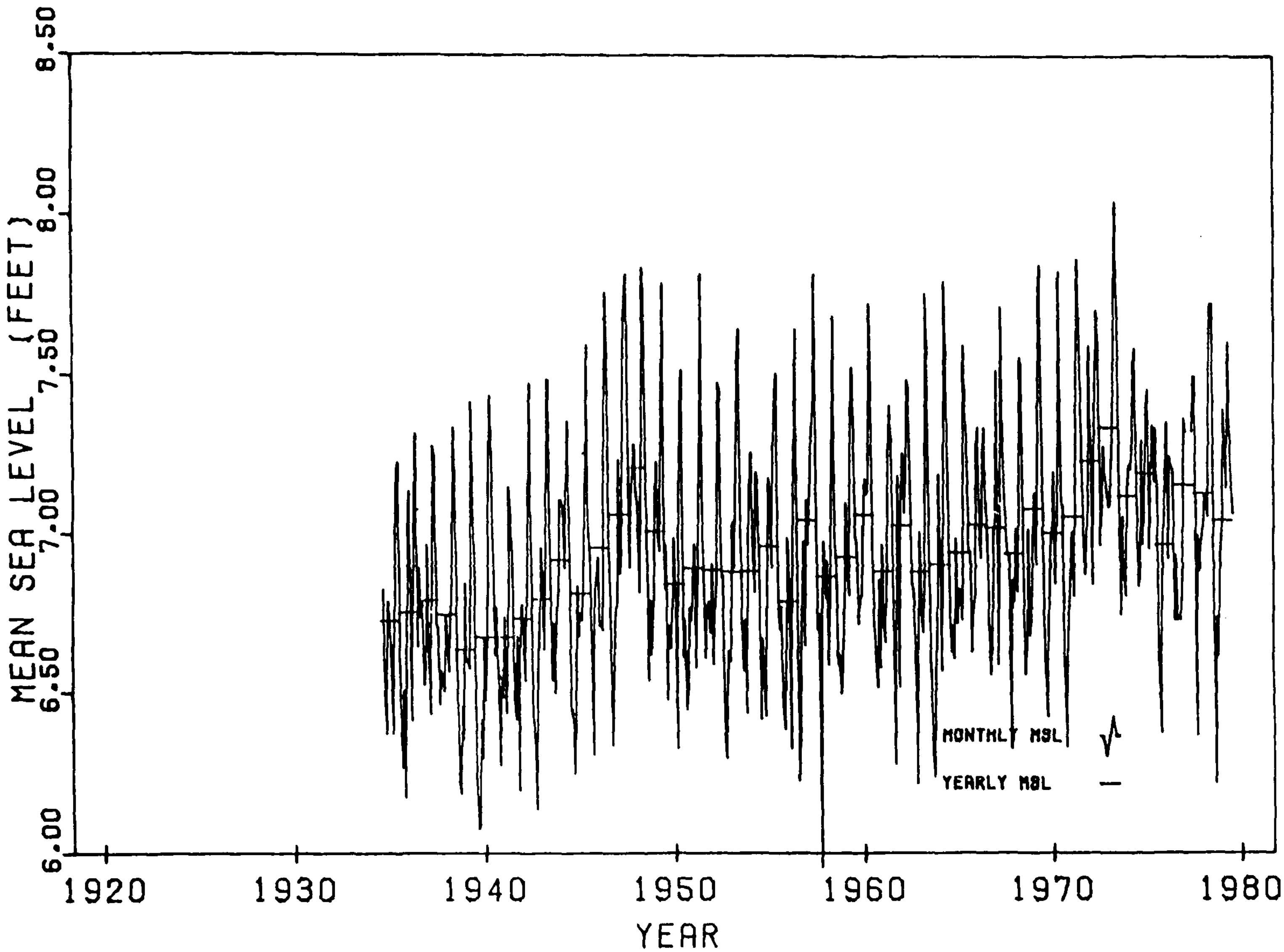


Figure 4. Rise in MSL at Fort Pulaski, Georgia

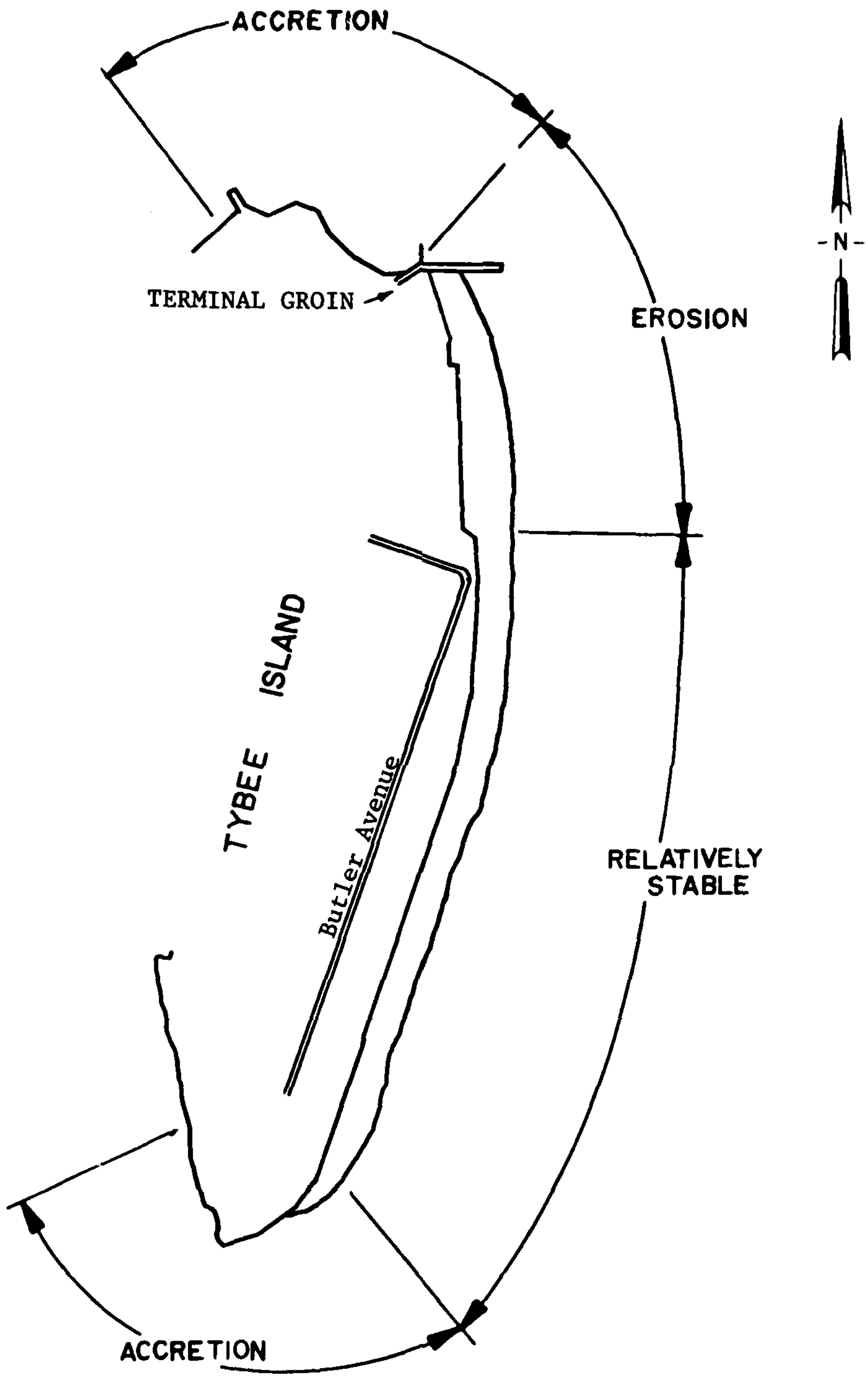


Figure 3. Portions of Tybee Island which have typically eroded or accreted prior to 1970

material caused accretion in the northern and southern extremities of Tybee Island (Figure 3). Following construction of the bulkhead, erosion was confined to the area seaward of the structure. This caused the beach surface to be lowered and diminished the usable area of recreational beach.

7. Water levels also influence the degree of erosion by waves. The mean tidal range at Tybee Island is 6.8 ft, with spring tide ranges sometimes greater than 9.0 ft. Wind-induced setup can increase normal water levels by as much as 3 ft, and when coupled with spring tide, water elevations have exceeded 11 ft above mean sea level (MSL) (Ebersole 1982; Office, Chief of Engineers 1973). Although the maximum reported peak storm water level at Tybee Island was 17.0 ft above MSL in August 1881 (U.S. Army Engineers District 1970), calculations (Appendix B) indicate that a hurricane equivalent to "Camille" could, under a particular combination of events, produce a peak surge greater than 20 ft above MSL (U. S. Army Engineer Coastal Engineering Research Center 1977). Such a storm would only occur every 500 years but could result in damages exceeding $10 million (Office Chief of Engineers 1973).

8. Since Tybee Island is bordered by the Savannah River on the north and Tybee Creek on the south, tidal currents influence the dispersion of sediment at the ends of the island. Patterns of shoreline advance and retreat in these areas have been related to changes in the areas of sediment transport through these tidal channels (Nummedal, et al., 1977; Oertel 1977).

9. Another important factor which influences the Tybee Island shoreline is the gradual rise in sea level (Figure 4). During the period 1936 to 1975 the sea level in the Savannah area increased at an estimated rate of 0.01 ft per year (Ebersole 1982). Over extended periods of time, this increase exposes new shoreline to erosion and decreases the total beach area available for recreation.

10. The changes in offshore topography since 1854 illustrate the effect physical processes have had on the subaqueous sediment platform associated with Tybee Island (Figure 5).

of concrete seawall between First and Center Streets and continued northward on the ocean side of the 1931 steel sheetpile seawall (Figure 10). The crest elevation of the top of the rock wall was about +11.0 ft MLW.

26. In 1963, the Chief of Engineers was directed by the US House of Representatives to perform a hurricane survey of the shores of Tybee Island. Subsequently, in January of 1970, the Savannah District released a report entitled "Tybee Island, Georgia Beach Erosion Control and Hurricane Protection" (U.S. Army Engineer District, Savannah 1970). The report indicated that the major erosion problem at Tybee Island was along the northern 8,300 ft, from the north end of Tybee Island to Ninth Street. The northern 1,000 ft of this section was experiencing shoreline recession, while the southern 7,300 ft protected by the seawall experienced erosion in the form of foreshore lowering rather than shoreline retreat.

US Army Corps of Engineers Project (1971-1976)

27. The 1970 Savannah District report became the basis for House Document No. 92-105 (Secretary of the Army 1971) authorizing a project which began in 1971. The project design was selected to serve two purposes: (a) the island was to be protected from normal tides and partially from severe storms and (b) the project was to provide "ample" dry beach area for present and future recreational needs. The design life of the project was 50 years. The plan for improvements required nourishment of 8,300 lin ft of shore beginning at the north end of Tybee Island and extending south to Ninth Street (Figure 11). A berm 60 ft wide at +11.0 MLW was designed to satisfy the present (1971) and future recreational needs of the area (Figure 12a). From the crest of the berm to +6.8 MLW, the beach slope was 1 on 20. From +6.8 MLW to the ocean floor the slope was 1 on 55. This design was based on estimated elevations of berms and slopes expected to be produced naturally by wave action. In 1971, the estimated annual beach nourishment requirement was 100,000 cu yd, and it was planned to use a 3-year advance supply of material.

28. The 1971 project recommended construction of three substantial rubble-mound groins with crest elevations generally following the beach slope. An 800-ft terminal groin at the north end of the island was established to maintain a "suitable" uniform beach alignment. Also, in order to

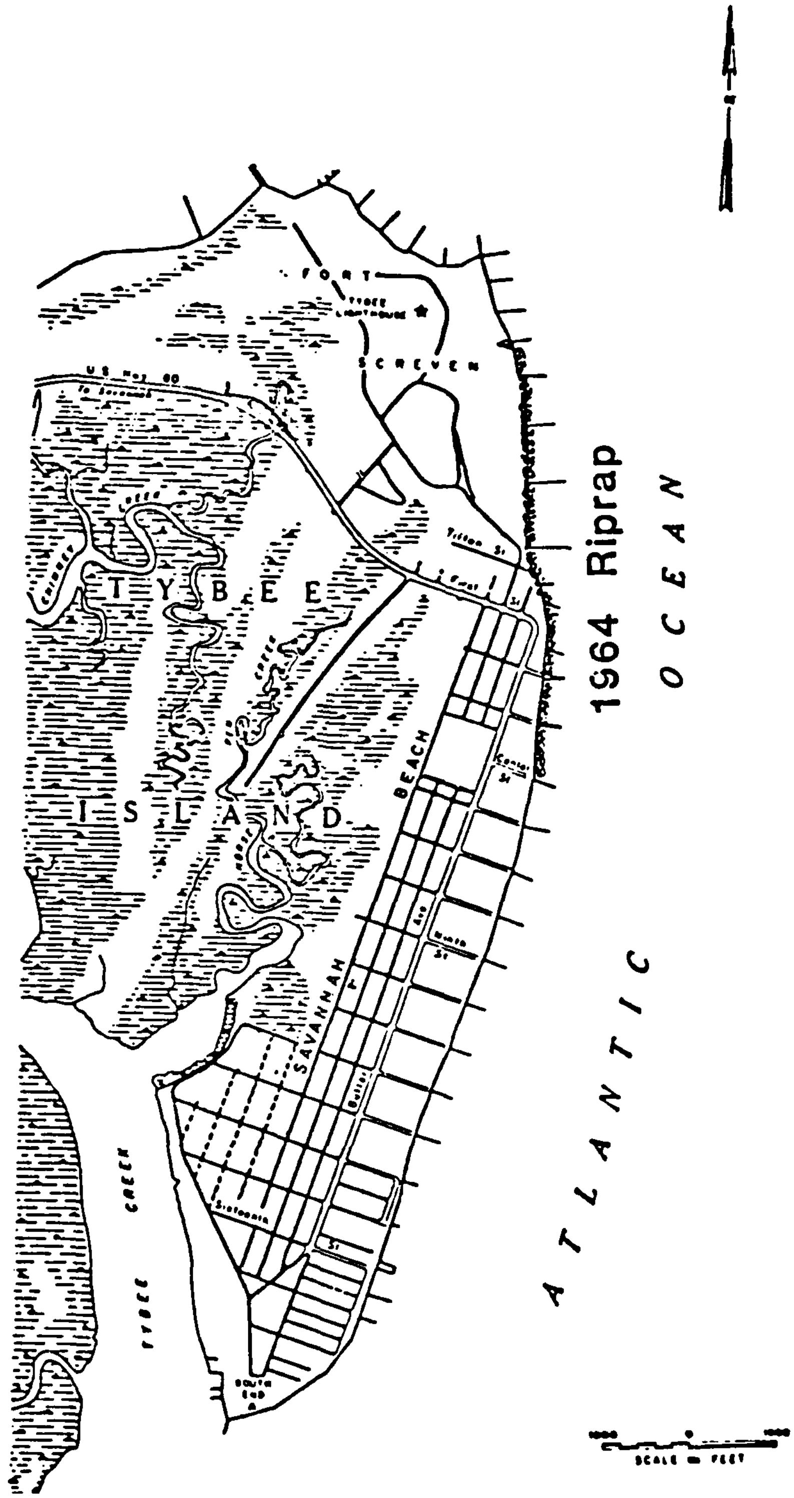


Figure 10. Location of emergency riprap protection placed in 1964

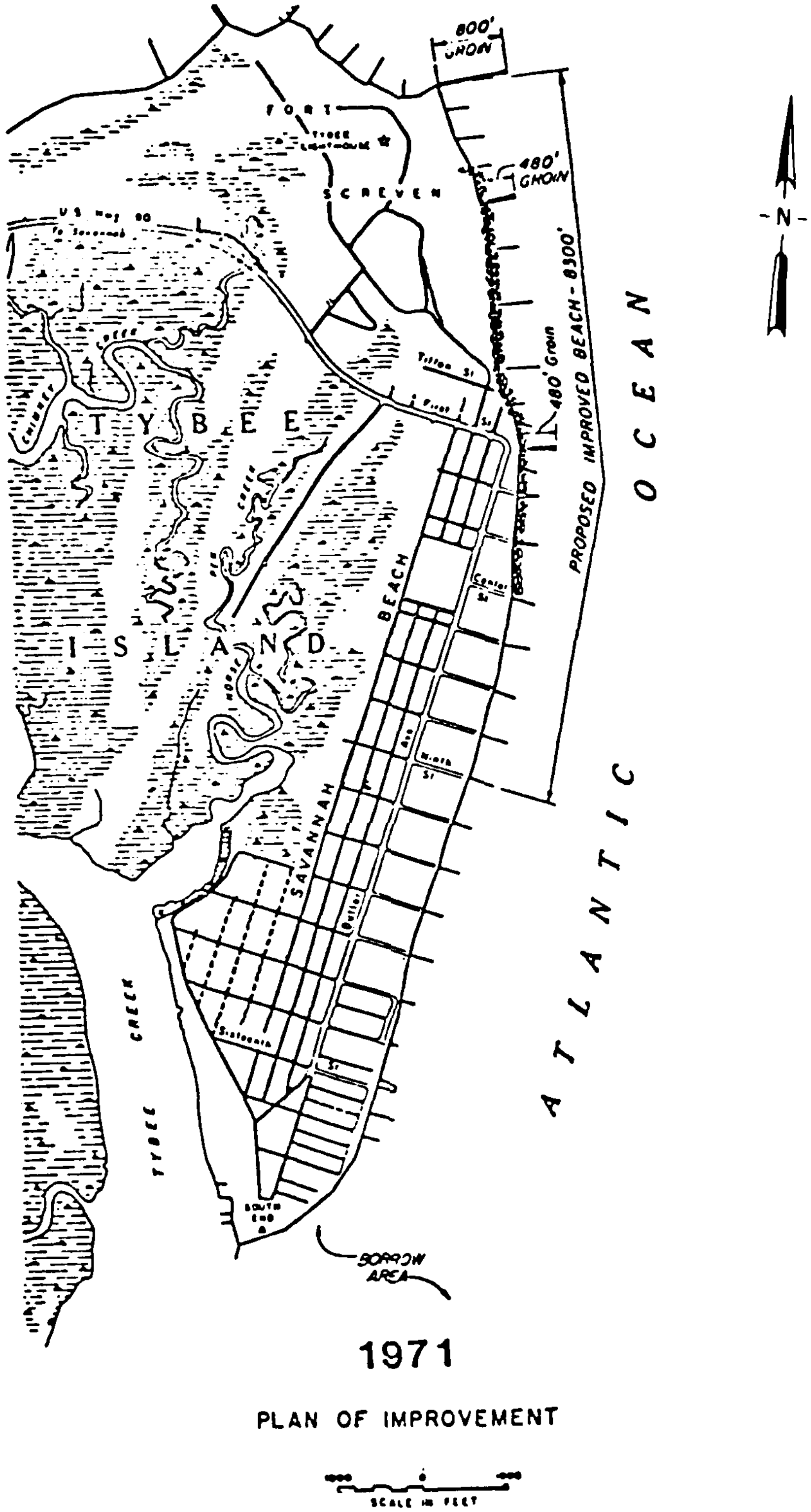
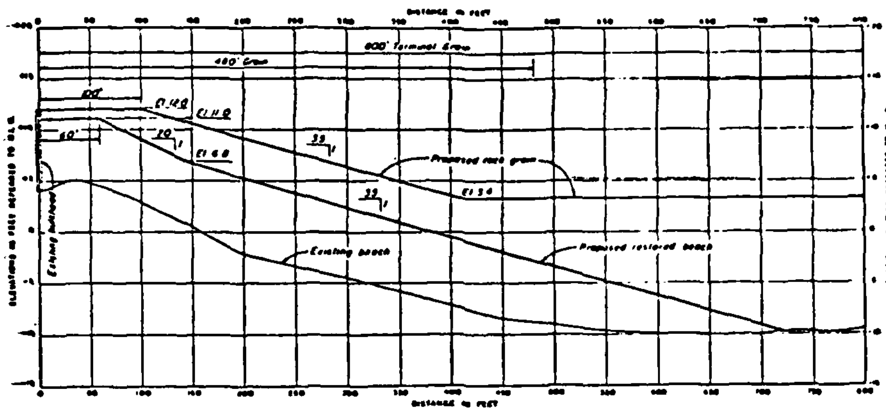


Figure 11. Proposed 1971 Corps of Engineers project limits

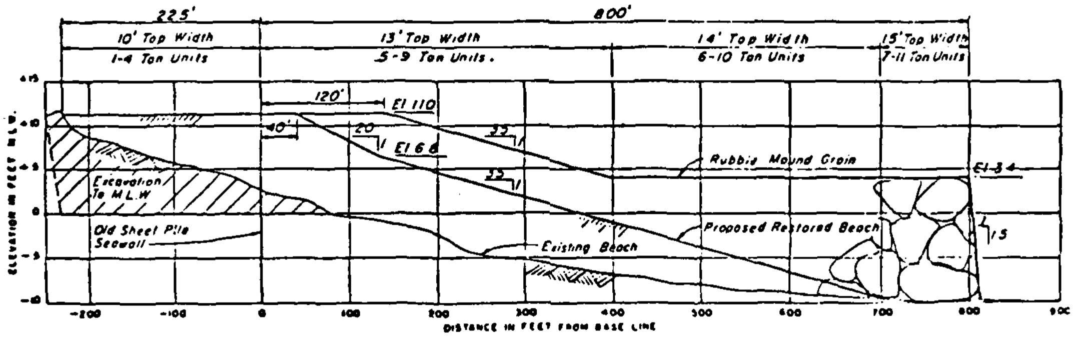
1971 Plan



PROFILES OF PROPOSED GROINS AND RESTORED BEACH

A

1973 Plan



PROFILE AT GROIN NO. 1 AND RESTORED BEACH

B

Figure 12. 1971 and 1973 plans for groins and beach profiles

"...reduce the northerly drift to a minimum," extension of the 800-ft terminal groin to a 2,000-ft length was deferred. The 800-ft groin was expected to prevent the "free" northerly movement of sand. Lengthening the groin would be justified by a projected reduction in the nourishment requirements. Two intermediate groins located 1,500 ft and 4,500 ft south of the terminal groin were also considered in order to reduce nourishment requirements and maintain uniform beach alignment (Figure 11). Groin crest elevations were set at +12.0 ft MLW for the shoreward 100 ft, with a 1 on 35 slope to +3.5 ft MLW, and remain at +3.5 ft MLW to the seaward end. The proposed cross section is shown in Figure 12a. This project was not built as initially proposed in 1971, as only the terminal groin was constructed.

29. In 1973, Design Memorandum 1 was prepared for the "Tybee Island Beach Erosion Control Project, Savannah Beach, Tybee Island, Georgia" (Office, Chief of Engineers 1973). The restored beach berm was designed to be 40 ft wide at +11.0 ft MLW, have a 1-on-20 slope between +11.0 ft MLW and mean high water (MHW) which is 6.8 ft above MLW, and a 1-on-35 slope to the existing bottom profile (Figure 12b). The estimated quantity of beach fill per linear foot of project was varied to produce a smooth project shoreline alignment. A modification to the recommendations in House Document No. 92-105 (Secretary of the Army 1971) called for a 4,000-ft southward extension of the project to Eighteenth Street (Figure 13). The total in-place fill for the project was estimated to be 1.295 million cu yd. This volume did not include any adjustments to account for the expected losses of fines, as that would be determined after the selection of borrow material.

30. Six potential borrow sites for nourishment material were sampled. The Tybee Creek Inlet site was selected. The median diameter of this material was 0.22 mm (fine sand), contained insignificant quantities of silt, clay, and organic material, and was slightly coarser than the grain size of the existing beach materials. Losses of fines during dredging and by winnowing were expected to be significant and were estimated by calculating critical ratios as outlined in the Shore Protection Manual (US Army Engineer, Coastal Engineering Research Center 1977). The critical ratio was determined to be 1.49, thus the initial volume losses were expected to be about 49 percent. This required the addition of 634,000 cu yd of borrow material to the project design. An additional 135,000 cu yd of borrow material were included as 3 years of advance nourishment. Since historical studies indicated that the

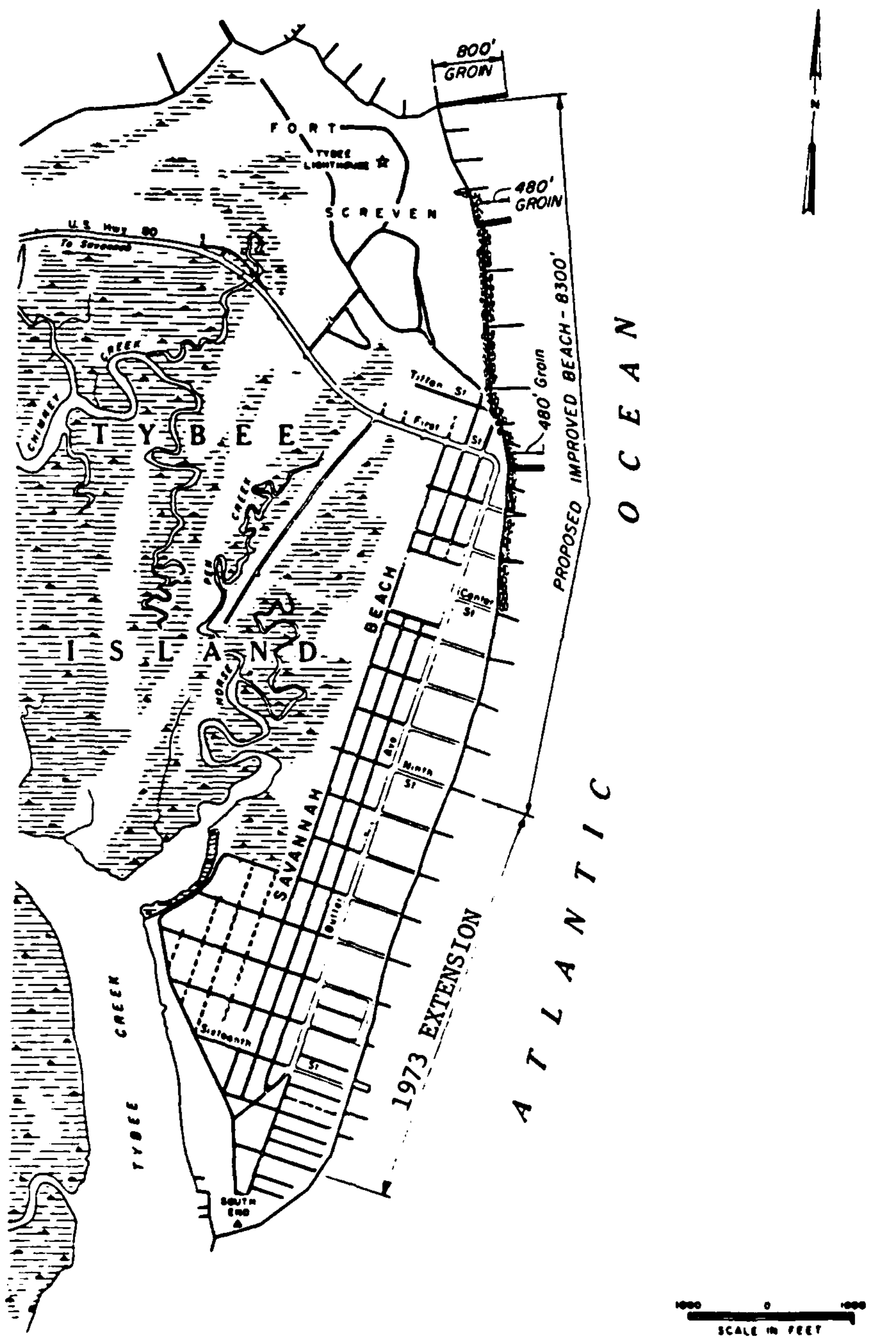


Figure 13. Proposed Corps of Engineers project nourishment limits and positions of proposed groins

greatest erosion rates had occurred at the north end of the island, 80 percent of the advanced nourishment material was placed at the north end of the project, between Second Street and the terminal groin.

Reach	Advance Nourishment, cu yd	Increase, ft, Beyond 40-ft Berm Width
Terminal groin to Second St.	108,000	29
Second St. to Ninth St.	27,000	21
Ninth St. to Eighteenth St.	0	0
Total Advance Nourishment	135,000	

31. The total in-place fill including advance nourishment, expected initial losses, and template requirements was 2,064,550 cu yd. Work was initiated on the terminal groin in the fall of 1974 and was completed in June 1976. Beach restoration began in late summer 1975 and was completed in early spring 1976. Approximately 2,262,000 cu yd of sand fill were actually placed within the project area which extended approximately 13,600 ft south of the terminal groin. The average widths of dry and wet beach were 357 ft and 524 ft, respectively.

Needs for design dimensions	1,295,000 cu yd
Losses expected after winnowing of fines	634,550 cu yd
Advance nourishment	135,000 cu yd
TOTAL	2,064,550 cu yd
Backfill behind north end of project baseline	197,450 cu yd
Total Placed	2,262,000 cu yd

32. Calculations for the period between 1920 and 1964 indicated an erosion rate of 45,000 cu yd per year for the entire project area. However, since the majority of these erosion losses were thought to be storm related, renourishment requirements were to be determined by periodic monitoring.

33. The 1971 design for the terminal groin was modified in the 1973 General Design Memorandum (GDM) (Office, Chief of Engineers 1973) (Figure 14). While the seaward length of the terminal groin remained 800 ft, the new design had a 225-ft landward extension. The original design for the terminal groin was developed using criteria presented in Technical Report No. 4, "Shore Protection Planning and Design" (US Army Engineers Coastal Engineering Research Center 1966). The terminal groin consisted of a single layer of

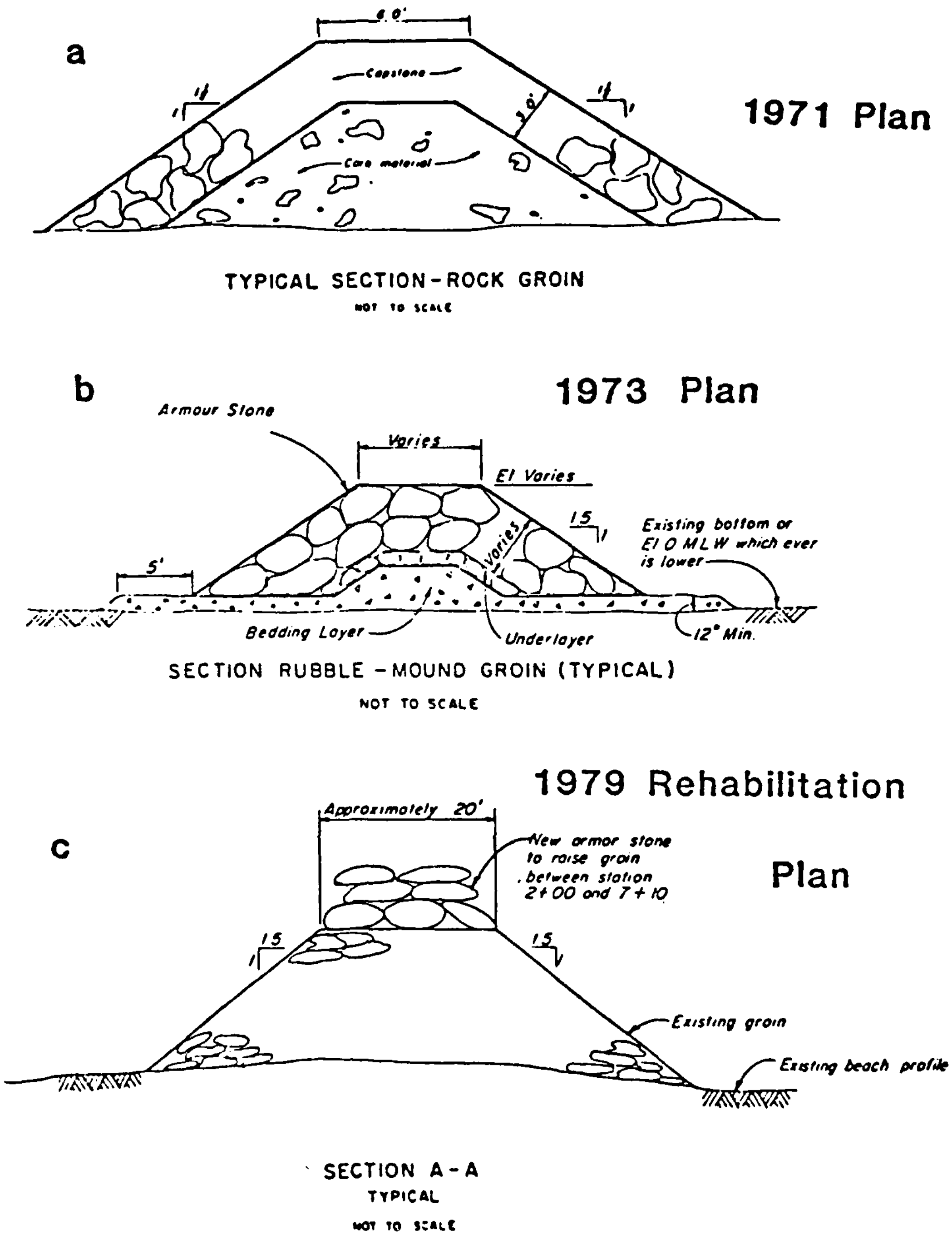


Figure 14. Proposed groin sections for 1971, 1973, and 1979 plans (Office, Chief of Engineers 1973, 1981)

armor stone placed over an underlayer and bedding layer (Figure 14b). The base of the groin was 0 ft MLW and the crest width varied from 10 to 15 ft. Based on a 6-ft breaking wave at the baseline (which was the 1912 "Old Seawall") and an 11-ft breaking wave at the seaward end of the terminal groin, four different size ranges of armor stone were used for construction of the terminal groin. Stones weighing from 1 to 4 tons were used landward of the baseline; 5- to 9-ton stones were used for the initial 400 ft seaward of the baseline; 6- to 10-ton stones were placed 400 ft to 800 ft seaward of the baseline, and 7- to 11-ton stones were placed at the groin head. The weight of the underlayer and bedding layer stones was 1/10 and 1/200 to 1/400 of the armor layer stone weights, respectively (Office, Chief of Engineers 1973).

US Army Corps of Engineers Rehabilitation Plan (1979)

34. During and subsequent to the 1971-1976 Corps of Engineers project, a shoreline monitoring program was employed to determine the effectiveness of erosion control structures at Tybee Island (Office, Chief of Engineers 1979). The monitoring program consisted of quarterly surveys taken of 35 profile lines (Figure 15). These surveys indicated that the beach fill losses exceeded the originally estimated quantities. In addition, the area of beach above MHW had decreased while the area above MLW had increased. This resulted in an increase of the wet beach area between MLW and MHW and a decrease in the slope of the wet beach. The south end of Tybee had experienced a large amount of erosion, the original berm placed between Eighteenth and Sixteenth streets was gone, and at high tide the beach was totally submerged.

35. In response to these findings, a rehabilitation plan for the Tybee Island shoreline was developed and submitted in August 1979 (Office, Chief of Engineers 1979). Major components of the plan included:

a. Rehabilitation and modification of the existing north end terminal groin using similar materials. The crest on the outer portion of the groin would be raised to +6.8 ft MLW. A weir section 75 ft long with a crest of +4.5 ft MLW would be included in the structure to pass sand to the beach north of the groin.

b. Construction of a new terminal groin at the south end of the project using reinforced precast concrete sheet pile with rock toe protection. The main functions of the groin were to: (1) serve as a "holding" structure for retaining sand in the project area on the upper foreshore and backshore, (2) divert tidal and coastal currents, thus preventing the landward migration of inlet channels,

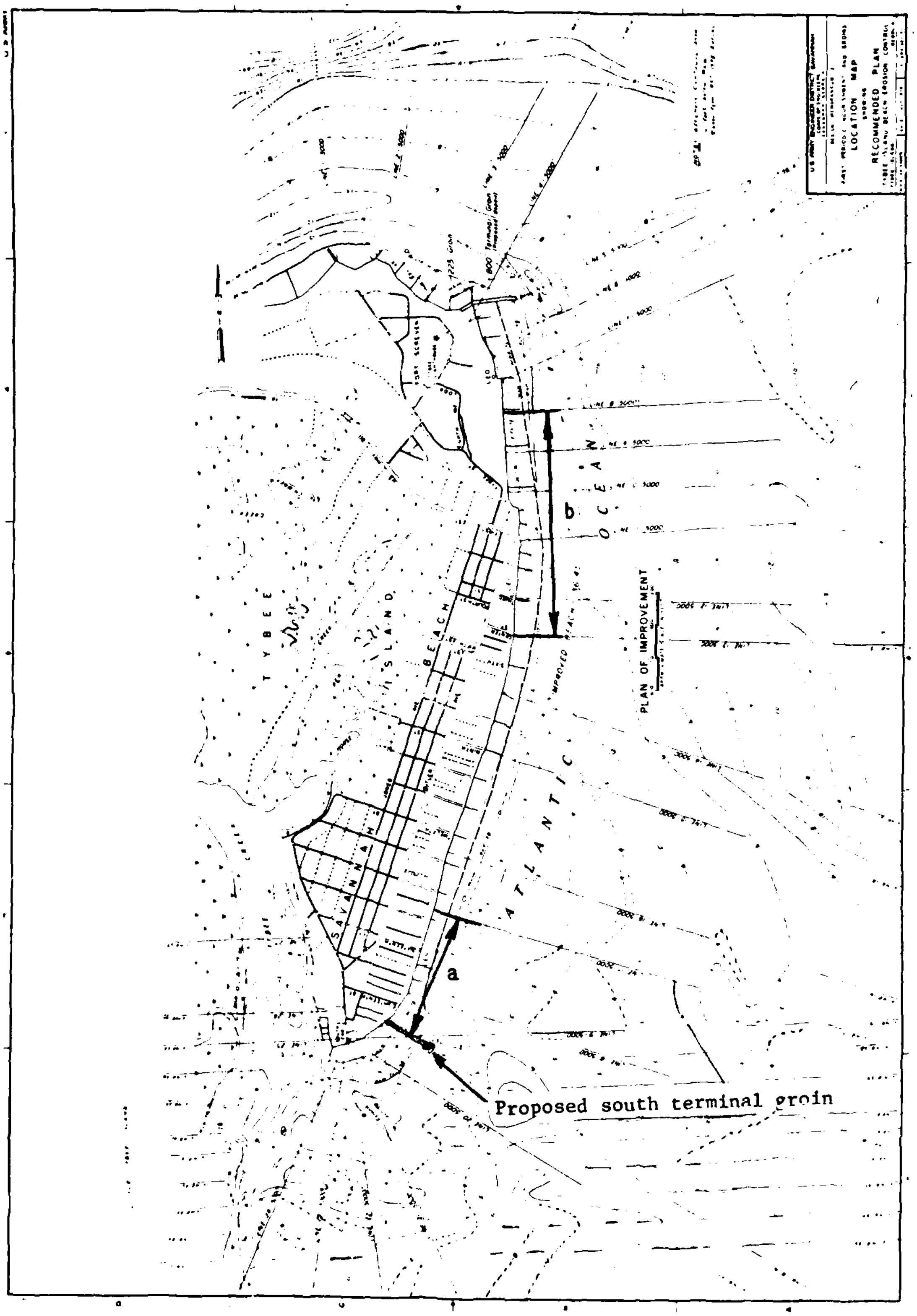


Figure 15. Location of survey lines for monitoring program and proposed locations of south terminal groin and replenishment areas

and (3) allow a specified amount of sediment from the upper foreshore to move onto downdrift beaches to preclude adverse effects to the southern tip of the island. Figure 16a gives details of the groin as shown in the GDM (Office, Chief of Engineers 1981). The groin would be located 400 ft south of Eighteenth Street and run approximately 800 to 900 ft out from the existing seawall. The crest elevation would vary from +10 ft MLW at the wall to elevation +1 ft MLW at the seaward end. A weir notch, 75 ft long with a crest at mean tide (elevation +4.5 ft MLW), would allow about 40 percent of the current sand losses to continue feeding the beach on the southernmost part of the island.

c. Beach replenishment included about 278,000 cu yd of sand on the south end of the island and about 394,000 cu yd in the vicinity of First Street (Figure 15). The large sandbar southeast of Tybee Island would be used to obtain material for replenishment.

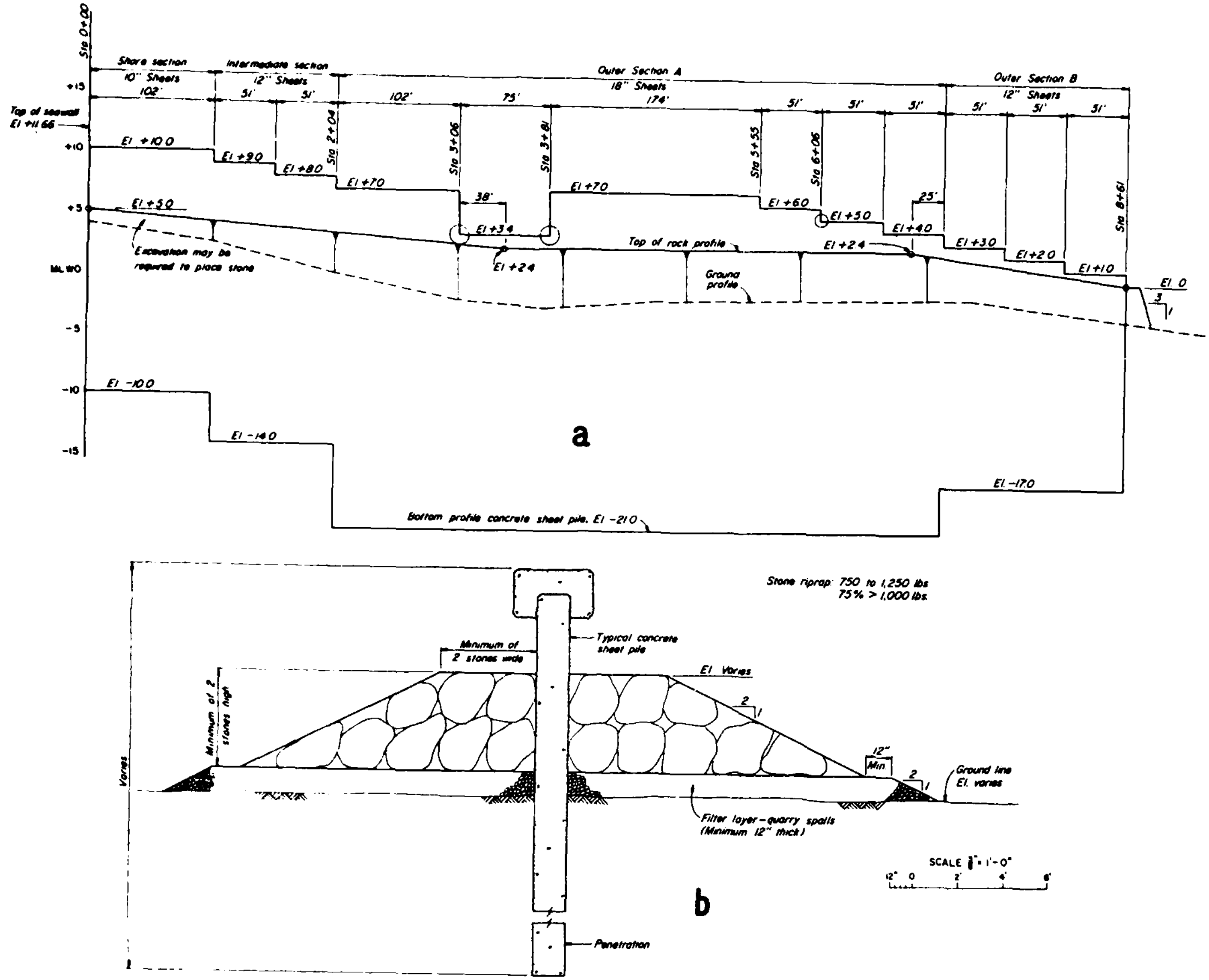


Figure 16. Profile and cross-section of proposed terminal groin at south end of Tybee Island (GDM 1981)

PART III: REPORTS ON EROSION CONTROL PROJECTS AT TYBEE ISLAND

36. By 1964, the entire ocean face of Tybee Island was protected by structures. A steel sheetpile bulkhead fronted by quarrystone armor was north of Center Street and a vertical concrete bulkhead was south of Center Street. A total of 24 groins were established along the foreshore to act as sediment traps (Figure 17). Following is a discussion (based on various reports and data available) of the many erosion control projects which have been undertaken on Tybee Island.

Gill Report, 1931

37. Gill (1931) provided a cursory evaluation of the 1930 beach erosion control project which was constructed along the Fort Screven shore. This project consisted of a 2,650-ft section of steel sheetpile bulkhead and five groins. His evaluation of the project was based on a survey taken 6 months prior to start of construction, observations made during the construction period, and a survey made at completion. Observations following construction of the first groin indicated a rapid buildup along the low water shoreline. A more complete survey 6 months later showed a considerable buildup along the entire shore. Gill also indicated, however, that there were "unbalanced conditions of erosion and accretion between respective groins," which he believed to indicate that the groins should have been placed closer together.

WPA Projects

38. The 1933 plans for modifying the 1930-1931 project determined that approximately 100 lin ft of the old bulkhead was apparently underdesigned for the wave forces. To remedy this, projects of the WPA in 1939 through 1941 employed improved design standards including use of concrete bulkheads and timber groins. After evaluating previous protective structures, the Savannah District felt that the most effective method of shore protection was a combination of bulkheads and groins, with "bulkheads for shoreline protection and groins for beach building purposes" (microfilm from Savannah District 1939). Attention was also given to the "type of design" and "structural strength"

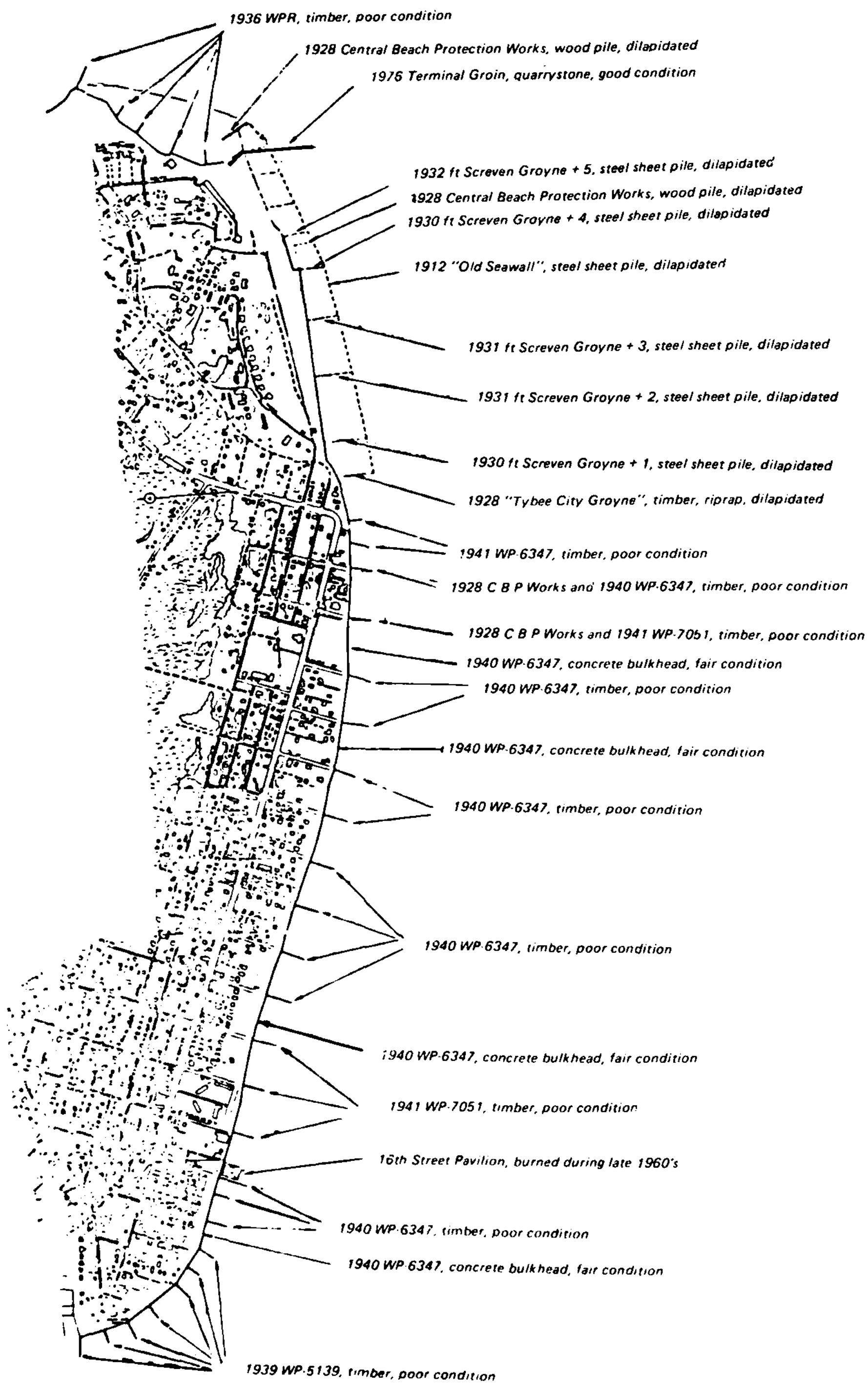


Figure 17. Locations, dates of construction, and present condition of previous shore protection efforts

seawall on the south end, another is between Little Tybee Island and the large sandbar 3,400 ft offshore, and the third channel is between this bar and the submerged shoals off the southern end of Tybee. As the tide begins to flood, the flows are basically confined to the three channels flowing into the inlet. During the first 4 hours of the flood tide, most of the water flows from the ocean through the middle channel and into Tybee Creek. At this point, approximately equal volumes of water flow through each channel and a small percentage flows over the shoals. During the last hour of the flood tide, 59 percent of the water flows through the channel which is parallel to Little Tybee Island. As indicated in Figure 22, during the maximum ebb tide, which occurs 2 hours after high tide, approximately 7 percent of the flood volume flows out the channel nearest to the beach, and about 46 percent of the volume flows through each of the other two channels. As the water flows along the beach front in the nearshore zone, it carries sand in suspension. On the flood tide, this sand is carried in the channel nearest the southern tip of the island and into Tybee Creek. As the tide begins to ebb, the suspended sand then flows out of the other two channels and bypasses the channel flowing along the beach. Some of the sand settles out in the inlet area developing sandbars, and some is placed back into the littoral drift system and is transported south to Little Tybee Island. The floats released beyond the breaker zone verified that a flood-dominated channel exists relatively close to the beach. Historical photographs indicate that this channel will migrate into and away from the shoreline. This in turn will determine the size and shape of the beach of the south end of Tybee.

Refraction Analysis

52. A refraction analysis was conducted based on LEO and data from the recording wave gage near the Tybee Light Tower (Weggel 1979). Three distinct waves were investigated and taken to be characteristic of the area: (a) locally generated short period waves (T = 2 sec) of low amplitude (H = 1.5 ft and H = 2.0 ft), (b) long period swells (T = 8.5 sec) from the southeast of low amplitude (H = 2 ft), and (c) fall and winter storm waves with short wave periods (T = 5.5 sec and T = 6.5 sec) of moderate height (H = 4.5 ft and H = 5.5 ft). The refraction analysis indicated that locally generated waves (from east and southeast) were not affected by offshore bathymetry beyond -10 ft MLW, that waves from the northeast caused a southerly longshore current flow, and that waves from the south produced the predictable northerly longshore current flow. Long period waves of relatively low amplitude generally (from east and northeast) broke at the foreshore, and initial refraction of wave crests began considerable distances offshore. Refraction caused a divergence of wave crests away from the central part of the island, resulting in a

he project area by stabilizing the backshore, sand flats, and dunes; and hird, increase overall sand retention by constructing a terminal groin at the outh end of the island.

Posey and Seyle, 1980

49. An evaluation of the Corps of Engineers' project and a summary of he special study on the accelerated erosion at the south end of Tybee Island ire given by Posey and Seyle (1980). The authors state that in the 52 years rior to initial beach nourishment in August 1975, "the northernmost 5,800 ft of beach had eroded at a rate of 5.7 horizontal ft per year" while "the idjacent 3,200 ft southward eroded at an annual rate of 2.9 ft horizontally andward." Completion of the terminal groin and beach nourishment in March 1976 increased the average width of dry beach at MHW from 87 ft to 357 ft, and he average width of wet and dry beach at MLW from 284 ft to 524 ft. By 1979 he total beach surface area at mean low water had increased from 4.0 million sq ft in 1975 to 6.65 million sq ft.

50. The surface area above MHW increased from 26 percent of the total beach at MLW to 51 percent during the period 1975-1979. This indicates formation of a steeper beach which is more vulnerable to erosion. In the 43 months after May 1976, approximately 460,140 of the 2,262,000 cu yd of nourishment material had moved out of the project area (approximately 128,400 cu yd per year). Approximately 339,400 cu yd of this loss migrated over, through or around the terminal groin and accreted just north of the project limits. The remaining 120,740 cu yd was either transported offshore or was transported to the south accumulating in the shoal areas near the southern end of Tybee Island.

51. Approximately 6 months after completion of nourishment, the southern end of the island began to experience an increased erosion rate, and by the summer of 1978, approximately 62 percent of the initial fill placed along the southern 2,100-ft project had eroded away. The 1978 Savannah District study was conducted to determine the causes for this accelerated erosion. The following summary of the results of the study is adapted from Posey and Seyle (1980).

> Results from the study indicated that the three channels flow into Tybee Creek with some water passing over the sandbars during the higher stages of the tide. As shown in Figure 22, one channel is within 600 ft of the

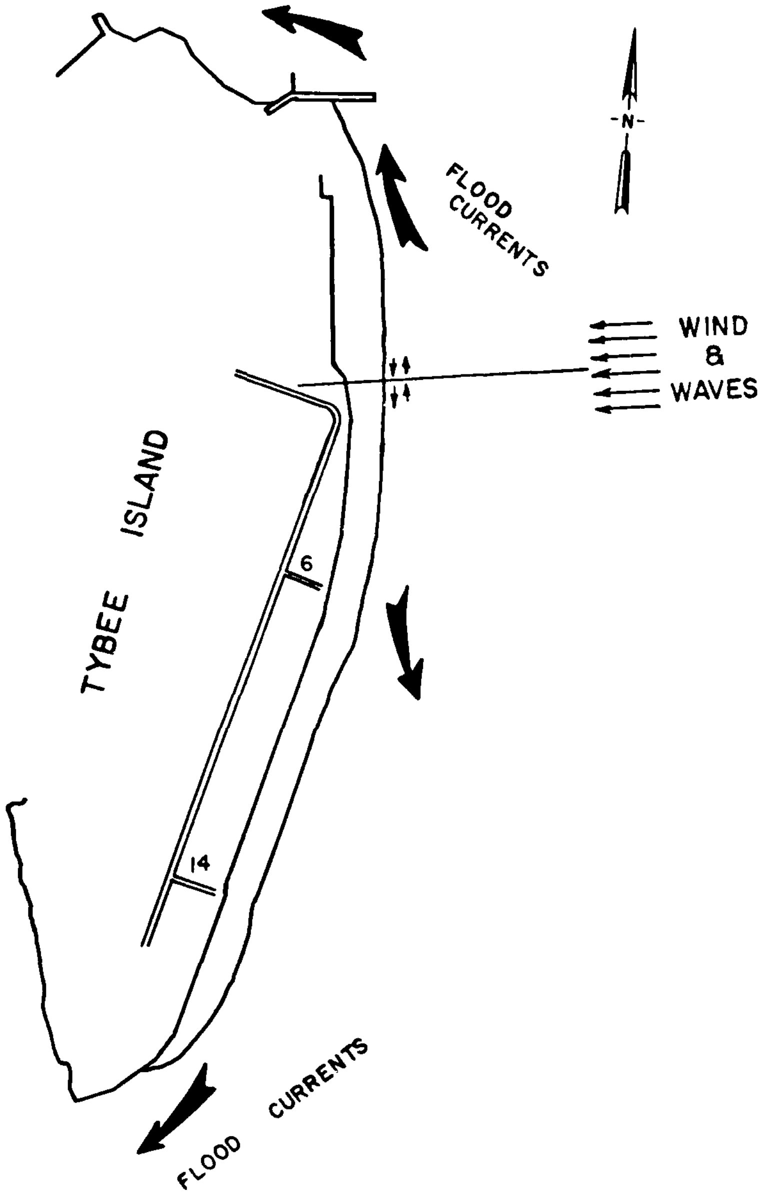


Figure 24. Directions of longshore transport during periods when waves approach from east-northeast

Oertel Report, 1978

47. Oertel (1978a) evaluated project performance on the basis of four sets of beach profiles from 14 transects within and 13 transects adjacent to the project area. The study was funded by the Savannah District, US Army Corps of Engineers, and included 1976-1977 Littoral Environment Observations (LEO) data and historical charts showing long-term changes in the Tybee Island shoreface. Estimates from profiled data sets indicated that in August 1977 approximately 85 percent of the nourished material had remained within the project area (Table 5), with the remaining material accounted for in newly accreted spits at the north and south ends of the island. The center of the island was still accretionary (as reported in the 1972-1973 prenourishment survey by Oertel 1974), whereas the northern and southern ends of the island were eroding. LEO data were used to calculate that north of Third Street longshore transport was to the north approximately 68 percent of the time, whereas south of Third Street longshore currents flowed to the south approximately 67 percent of the time (Table 2, Figure 24). An excess of 150,000 cu yd of material was believed to have been transported over, around, and through the terminal groin. Approximately 100,000 cu yd of eroded fill was transported to a "cape-like" feature adjacent to Tenth and Twelfth Streets. Material eroded from between Sixteenth and Eighteenth Streets was transported southward toward Tybee Creek Inlet. Analysis of beach surveys and aerial photographs also showed that the terminal groin was not totally effective in holding nourishment material. Time-sequence photography at the north end of the island showed the accretion of approximately 10-12 acres of land along the shore just northwest of the terminal groin (Oertel 1978a). Material had migrated around and over the groin forming a spit which slowly migrated landward. Surveys of the groin in 1978 indicated that the groin had settled, reducing its effectiveness.

48. This report concluded that beach nourishment was an effective way to temporarily inhibit shoreline recession and provide a beach for recreation. Although the project was considered to be successful, the report stated that performance could probably be increased by improving the sediment trapping efficiency of the terminal groin and constructing more sand trapping devices. Three types of modifications were proposed: first, improve the effectiveness of the north terminal groin; second, prevent aeolian losses from

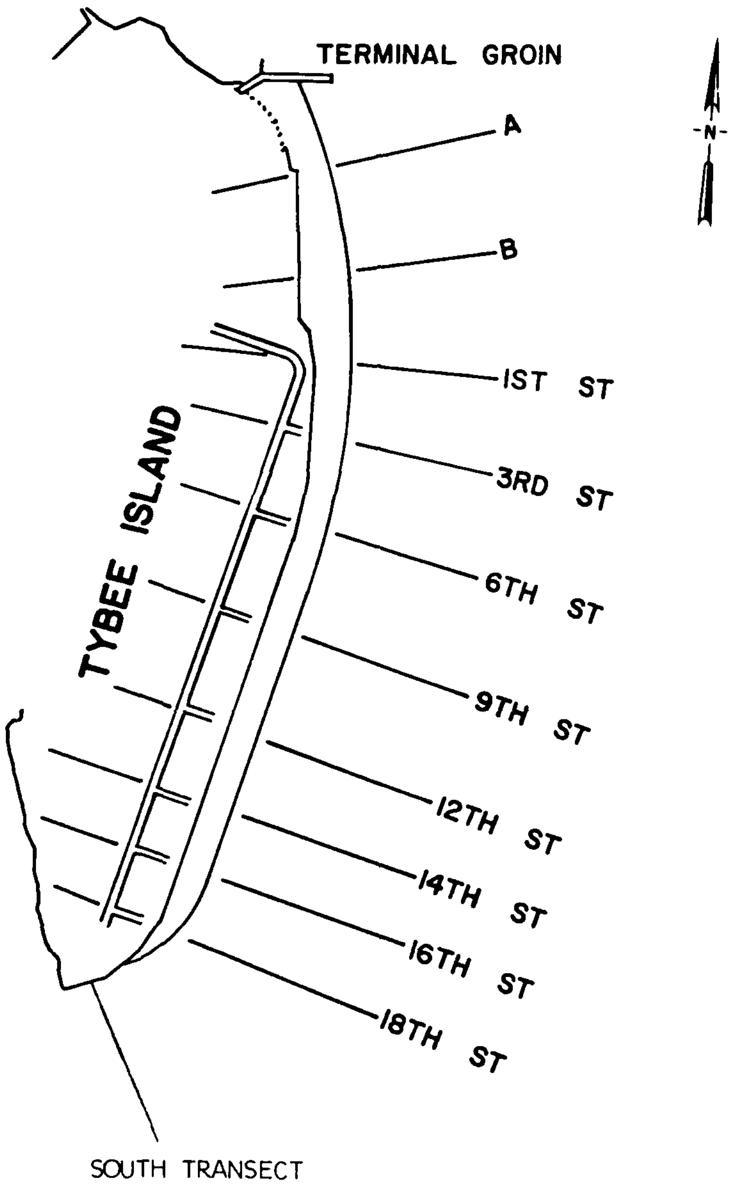


Figure 23. Location of 11 transects used in the 1976 Georgia Department of Natural Resources study

45. The Tybee Creek tidal channels have historically migrated, impacting on the morphological evolution of the southern end of Tybee Island (Oertel 1977). Data from the study showed that both the total ebb and flood tidal prisms through Tybee Creek Inlet were approximately 9 million cu ft (Table 2). Of specific interest to the project performance was the tidal channel on the northern side of the ebb tidal delta which flowed very close to the south end of Tybee Island. Tidal flow measurements indicated that the maximum flood through the northern channel was more than twice that of the ebb (Table 2), with the difference accounted for in the two other channels. Thus, the delta was transected by two ebb-dominated channels and one flood-dominated channel. The flood-dominated channel reinforced the southerly transport of sediment adjacent to the south end of Tybee Island (Oertel 1979b). Table 3 is a summary of the velocity data obtained during this study.

Georgia Department of Natural Resources Study

46. In 1976, the Georgia Department of Natural Resources funded a study utilizing aerial photography of the Tybee Island shore (Zisa 1978). Measurements were made along 11 transects from aerial photographs taken in April 1976, January 1977, June 1977, and February 1978 (Figure 23). The study indicated that the shoreline at the northern and southern ends of the project area was retreating. From the terminal groin to Third Street, the average shoreline retreat was approximately 38 ft per year. Between Twelfth and Eighteenth Streets the average shoreline retreat was about 61 ft per year. The central part of the island between Third and Twelfth Streets experienced an average shoreline advance of 27 ft per year. These estimates were all based on measurements of the approximate high water line position from aerial photographs. The report summarized that the project was apparently not performing satisfactorily since the surface area (dry beach area) added by nourishment had been reduced by 33 percent in 22 months. Table 4 presents a summary of the results of the study. Although it may be true that the placed dry beach area was reduced by 33 percent of its original size, this does not necessarily imply unsatisfactory performance. It is characteristic of beach fills that the "equilibrium" beach will have less dry surface area than the originally placed beach.

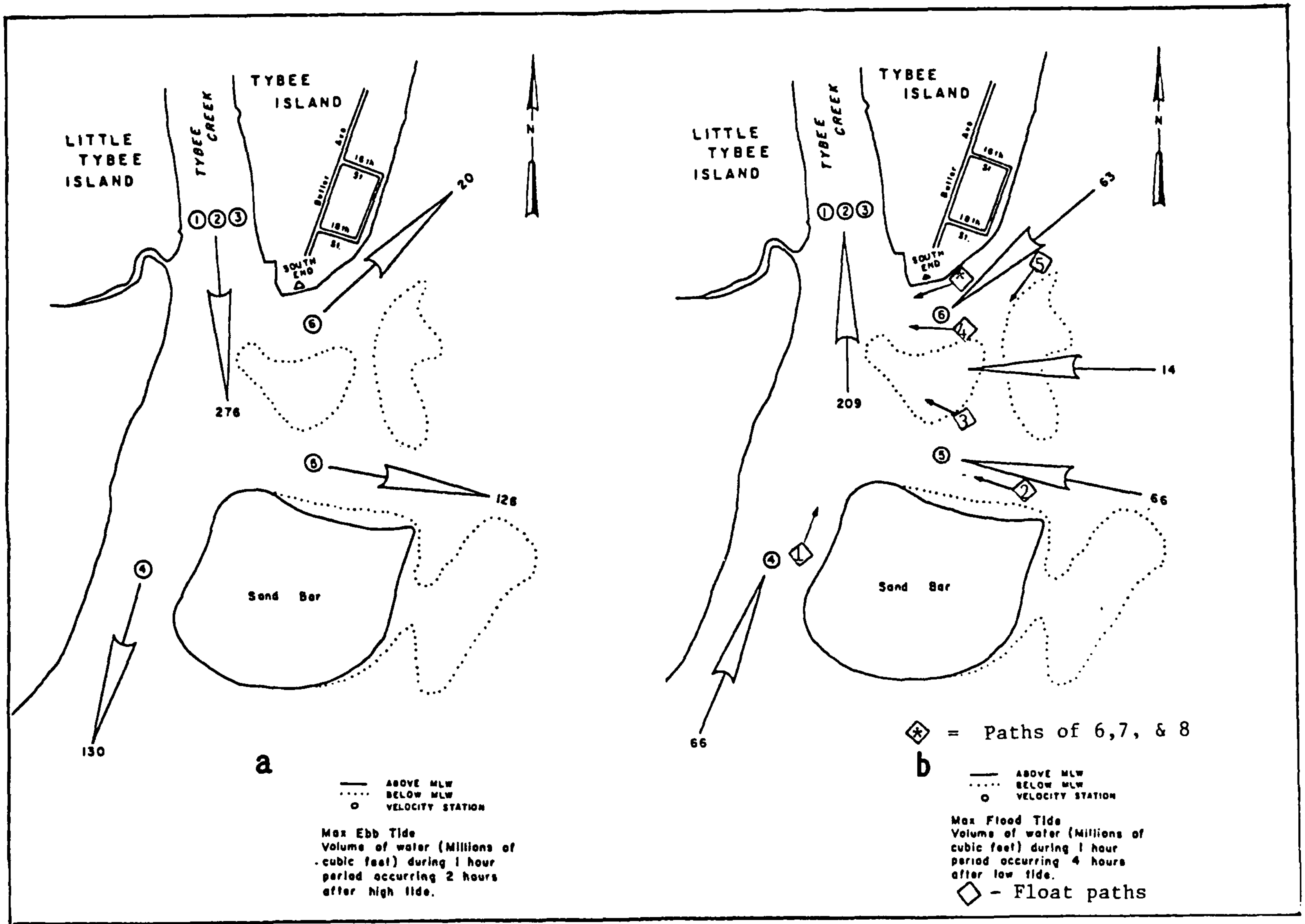


Figure 22. Location of three tidal channels near Tybee Creek and routes of float paths used in Corps of Engineers study (Posey and Seyle 1980)

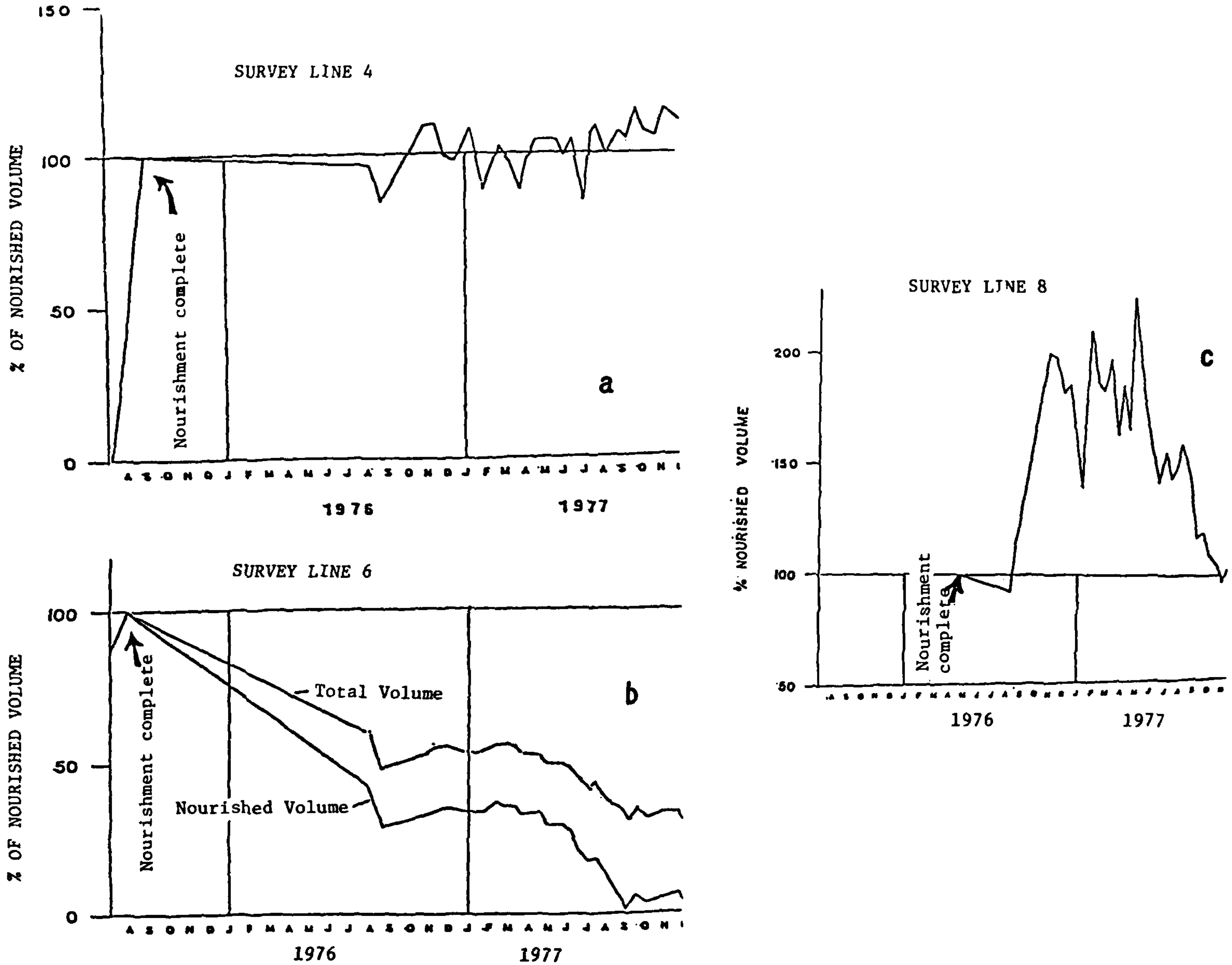


Figure 21. Monthly volume gains/losses at three locations

fill material. (The Savannah District monitoring program indicated a 20 percent loss during the same period.) The thirty surveys illustrated the magnitude of biweekly change along each transect relative to the long-term trends. Along "stable" areas of the shore (transects 3, 4, and 5) the biweekly changes, both erosional and accretional, were at times greater than the net change. (Figure 21a is typical.) At actively eroding areas (transects 6 and 7), biweekly changes were relatively small compared to net losses (Figure 21b). The biweekly data traced the creation and destruction of a sand spit at the south end of the island which had apparently been fed by material eroded from between Sixteenth and Eighteenth Streets (Figure 21c, transect 8). The same biweekly data indicated that erosional losses produced by the passage of Hurricane Dottie in August 1976 were recovered at each transect by November 1976. Evaluation of the sediment budget based on data from this study indicated satisfactory performance within the project limits. This conclusion was based on results from the transect measurements which indicated a loss of only 15 percent of the total beach fill as of August 1977. Erosion was confined to the north and south ends of the island, with the south end experiencing the greatest losses.

Accelerated Erosion at South End of Tybee Island

44. By early 1976, approximately 2.262 million cu yd of fill had been used to improve 13,614 lin ft of beach (Office, Chief of Engineers 1981). Approximately six months later the southern tip of Tybee Island experienced accelerated erosion, resulting in losses of a significant portion of the placed beach fill. In the fall of 1978, a special field study of the major eroding area at the south end of Tybee Island was conducted by the Savannah District; the US Army Coastal Engineering Research Center; Dr. George F. Oertel, Consultant; the Georgia Department of Natural Resources; and the City of Tybee Island. Concurrent with this work, a refraction analysis of waves approaching the shore of Tybee Island was conducted (Weggel 1979). This study was an attempt to characterize the processes causing the accelerated erosion. Dye packets and neutrally buoyant drifters were used to determine the path and speed of surface currents at various phases of the tide. In addition, discharge studies were made in Tybee Creek and the three tidal channels which dissect the ebb tidal delta of Tybee Creek (Figure 22a).

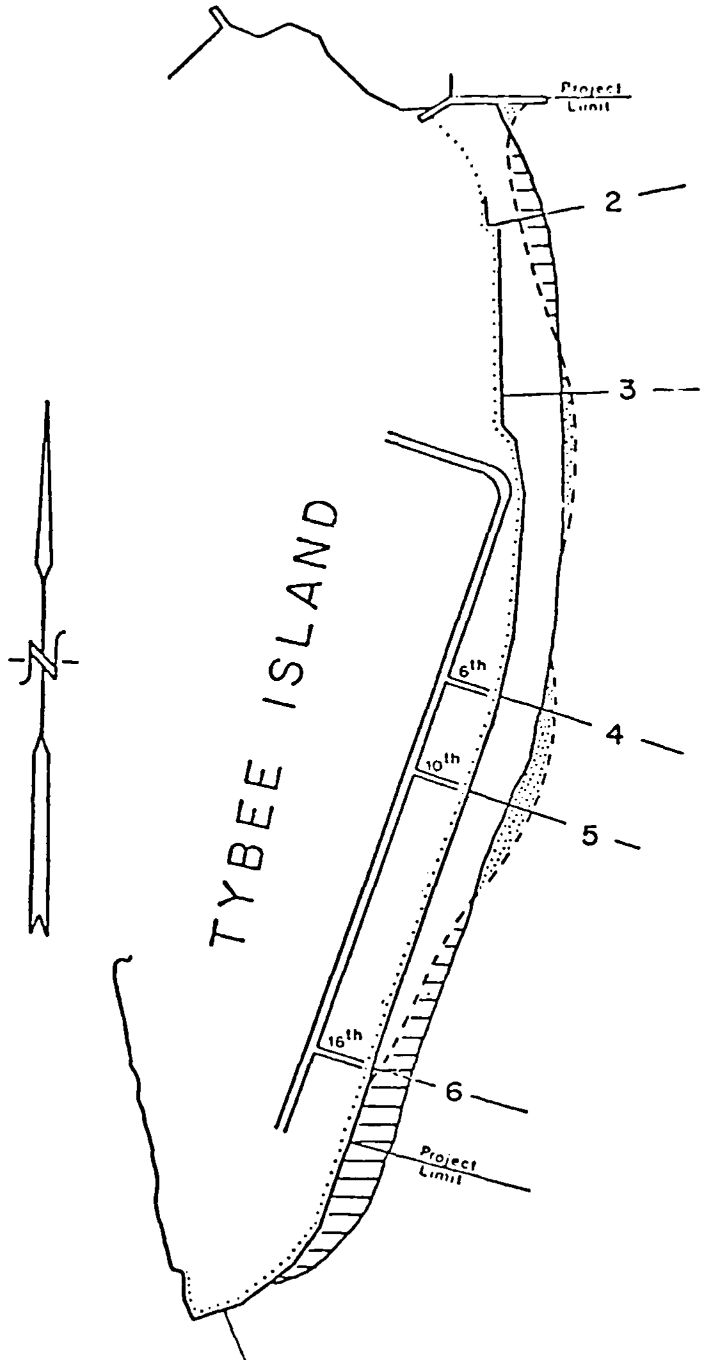


Figure 20. Locations of profile lines used in Skidaway Institute of Oceanography study

northern and southern ends of the island may indicate significant losses due to offshore sediment transport.

US Army Corps of Engineers Monitoring Projects, 1971-1984

41. The GDM (Office, Chief of Engineers 1973) for the "Tybee Island Beach Erosion Control Project" included a plan for the evaluation and maintenance of the project. This plan was developed in response to the belief that processes causing erosion at Tybee Island would continue and that periodic nourishment of beach material would be necessary to maintain the design profile. Since it was recognized "...that erosion will not occur at a uniform rate," beach nourishment was to be scheduled in conjunction with post-construction beach monitoring programs. Yearly inspections of the terminal groin were to be performed to determine variations from the project design and the need for maintenance to assure the continued function of the structure.

42. The monitoring program consisted of quarterly surveys (1975-1980) along fourteen profile lines established within the 13,614 lin ft of improved beach (Figure 15). The program also provided for surveys following severe storm events. The surveys indicated that losses of initial beach fill had exceeded the predicted quantities. Sand passing over the terminal groin accreted on the north side of the groin. Within the limits of the project there were pockets of erosion and accretion. The area of beach above MHW decreased, the area above MLW increased, and the slope of the wet beach decreased. Beginning in 1976, the south end of Tybee experienced a large amount of erosion. The original berm placed between Eighteenth and Sixteenth Streets disappeared, and at high tide water reached the bulkhead.

Skidaway Institute of Oceanography Study

43. In May of 1976, the Georgia Office of Planning and Budget sponsored a study conducted by the Skidaway Institute of Oceanography to monitor beach changes in the nourishment area (Oertel 1978c). Nine profile lines were established, five of which were within the project limits (Figure 20), and thirty biweekly surveys were obtained between May 1976 and January 1978. Results of this study indicated a net loss of only 10 percent of the original

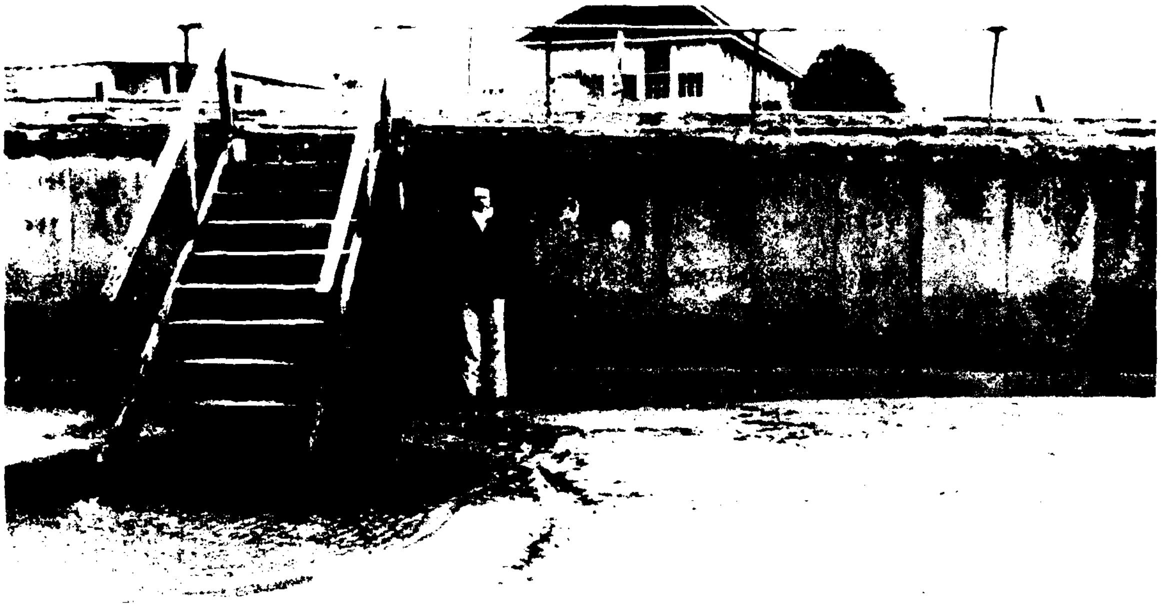


Figure 19. Lowering of the beachface in front of the concrete bulkhead

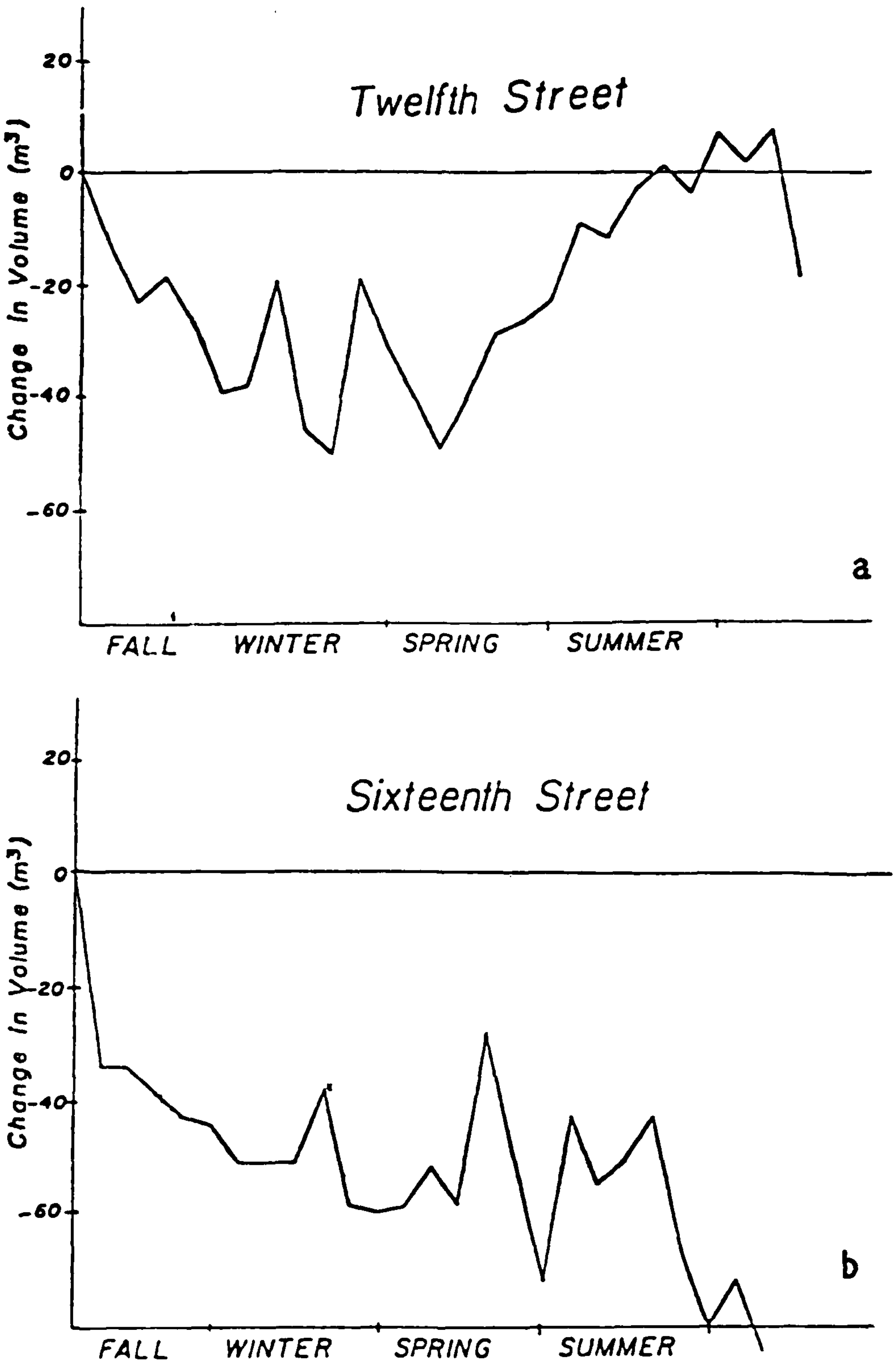


Figure 18. Seasonal sediment budget trends at two locations

needed for the protective structures, which resulted in concrete bulkhead construction taking the place of previously employed steel or timber bulkheads.

39. The structural performance of the Tybee Island bulkhead was again evaluated in 1964 following Hurricane Dora. A portion of the concrete bulkhead between First and Center Streets was damaged, and severe erosion at the base of the steel sheetpile seawall left that structure in danger of failure. The extreme lowering of the beachface seaward of the bulkhead threatened to undermine the concrete and steel walls, requiring quarrystone or riprap placement.

Georgia Sea Grant Study, 1972

40. In 1972, the Georgia Sea Grant program funded a study on sediment dispersion along the central part of the island between Sixth and Sixteenth Streets (Oertel 1974). The study was conducted during 1972-1973 utilizing standard beach profiling methods (Oertel, et al. 1979) at biweekly intervals. At Sixth, Ninth, and Twelfth Streets, fall and winter erosional trends were followed by spring and summer gains, resulting in a balanced annual sediment budget (Figure 18a). At Sixteenth Street erosion was relatively continuous (Figure 18b). The second phase of the study concerned movement of sediments between and around groins. Sediment transport was generally from south to north along the beach face, and the groins generally did not restrict alongshore transport. Fluorescent tracer grains moved from cell to cell, either around, over, or through the groins. In some areas the groins apparently formed rip currents that may have increased local erosion. Another finding of the study was that the seawall and groins along the ocean face of Tybee Island influenced the sediment budget in different ways. The seawall prevented the loss of property landward of the wall; however, erosion continued to lower the shoreface in front of the seawall (Figure 19). Although the groins were not highly effective for trapping sand or inhibiting erosional processes, the central part of Tybee Island had developed a substantial berm seaward of the seawall and apparently had a stable sediment balance in the mid-1970's. Erosion south of Sixteenth Street lowered the foreshore; however, the bulkhead prevented retreat of the shoreline beyond the bulkhead. The ineffectiveness of groins to trap and accumulate sediment at the

divergence of longshore currents (Figure 25). These wave-induced currents would tend to reinforce the flood tidal currents into adjacent inlets and inhibit the ebb flow from these inlets.

53. The refraction analysis also indicated that the impact of storm waves on Tybee Island was affected largely by the stage of the tide. During seasonal storms a relatively large amount of wave energy reached the upper foreshore and was concentrated at the ends of Tybee Island, particularly the south end. At low water, wave energy dissipation at the north end of the island was unaltered; however, the partial breaking of waves on the offshore shoals decreased the amount of wave energy reaching the foreshore at the south end. The longshore current produced by waves breaking offshore flowed through the tidal channels at Tybee Creek (particularly the northern ebb tide delta channel), increasing the tidal flood adjacent to the southern tip of the Island and resulting in scour of the upper shoreface. Appendix D contains the refraction diagrams generated from this study.

Griffin and Henry, 1984

54. In January 1982 the Georgia Geologic Survey funded a study (Griffin and Henry 1984) to develop a broad and comprehensive data base for Georgia's coast. Using maps and available aerial photographs the authors compiled a history of the Georgia MHW shoreline change from 1857 through 1982. Results of the study indicated that since 1857 the G. rgia coast has been dynamic but stable with the exception of St. Catherines and Tybee/Little Tybee Islands, which experienced net erosion. The authors claim that erosion at Tybee Island is directly linked to navigation and flood control projects on the Savannah River, specifically dredging operations and upstream dams. The study includes a figure (Figure 26) which shows the Tybee Island MHW shoreline positions for various years since 1857. The authors use this figure to demonstrate that prior to 1915, when dredging was begun on a regular basis, Tybee Island experienced net accretion. After this date, the figure indicates net erosion which the authors attribute largely to dredging, flood control, and soil conservation operations. The authors reference Oertel (1977) who estimates that since 1915 these operations have combined to remove approximately 0.65 billion cu yd of sediment from the system. Another study referenced by Griffin and Henry states that the beach and dune sands on Tybee Island are

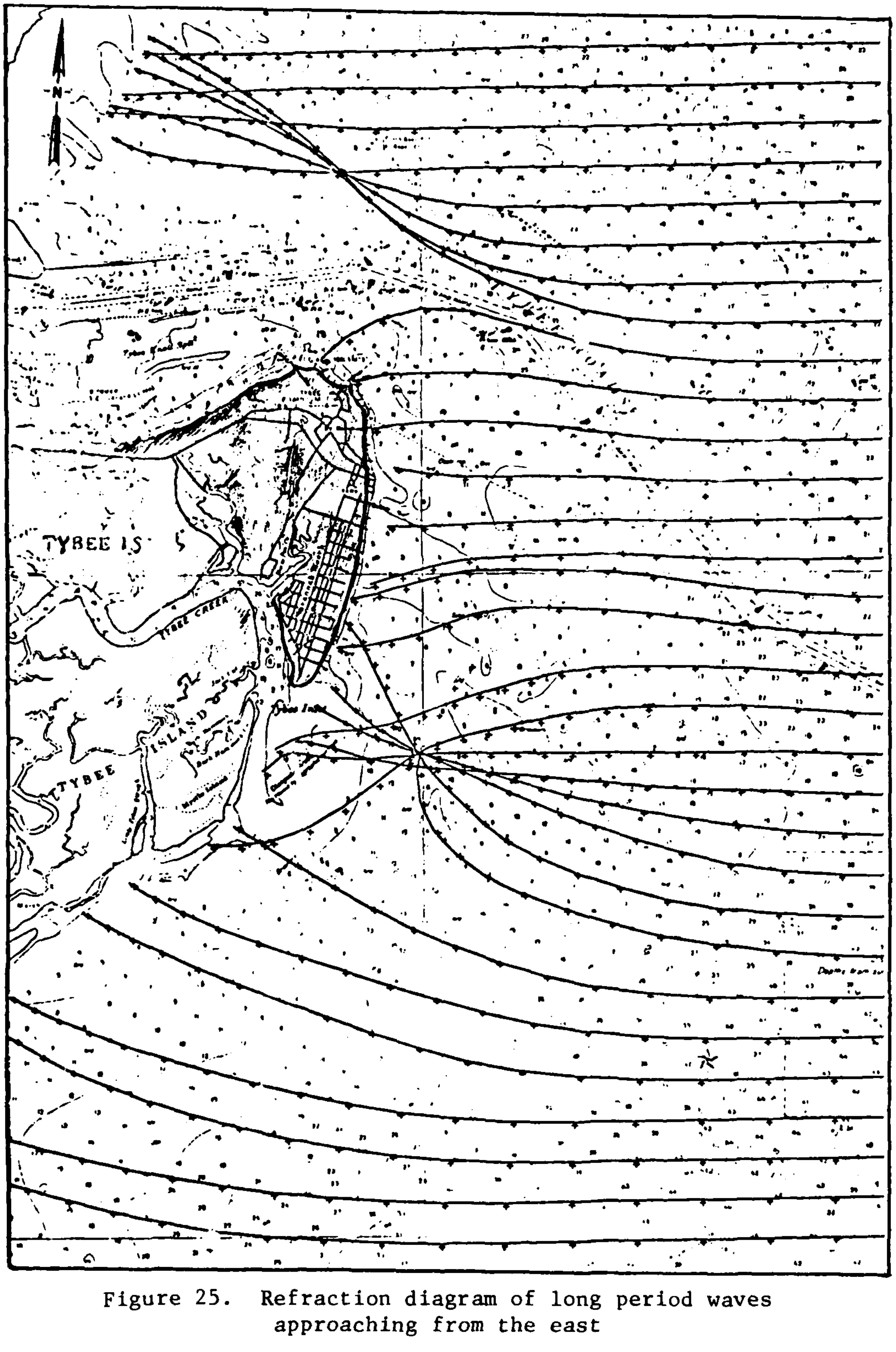


Figure 25. Refraction diagram of long period waves
approaching from the east

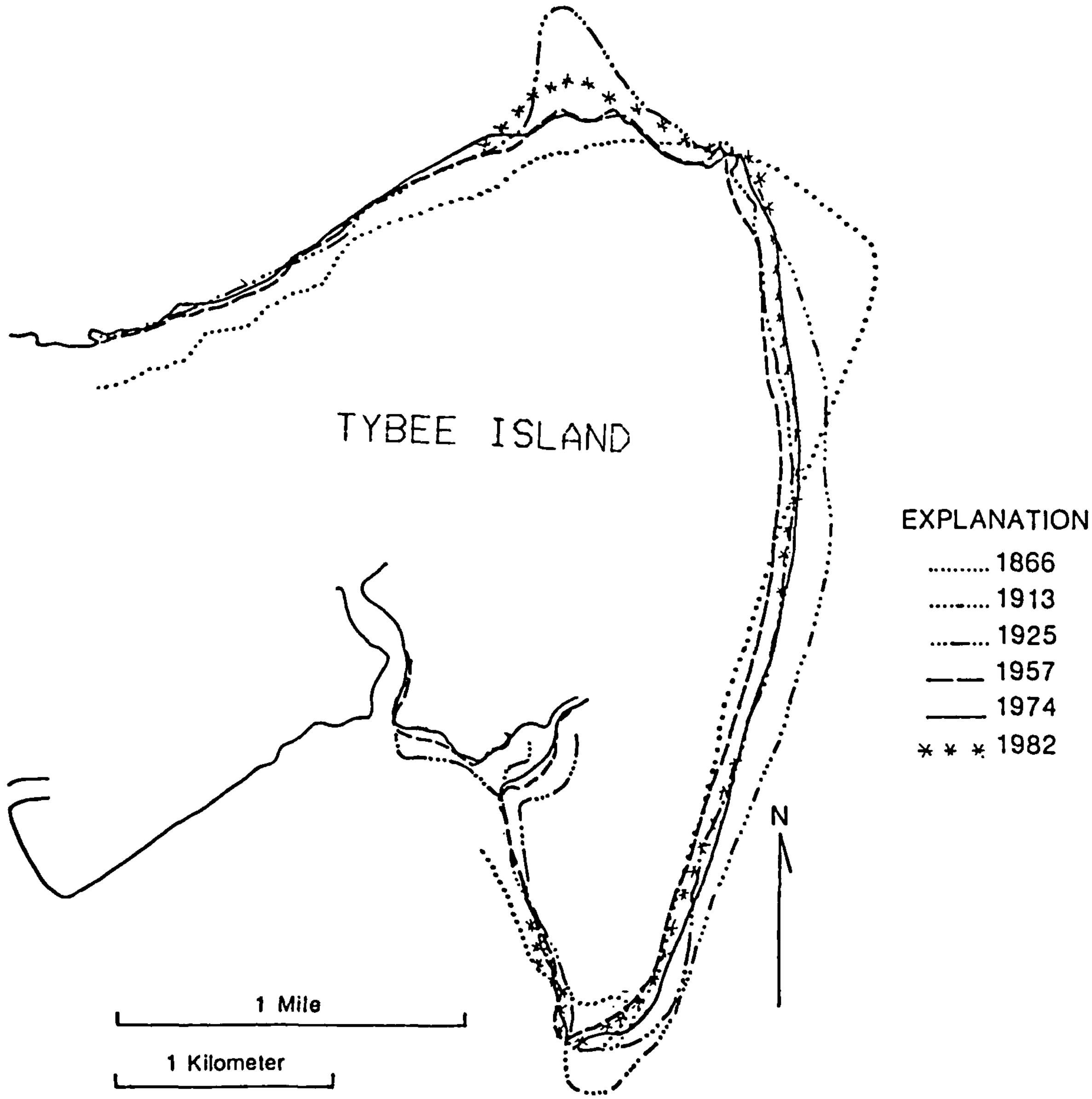


Figure 26. Figure used by Griffin and Henry (1984) to demonstrate shoreline movement

mineralogically very similar to those sands transported by Piedmont rivers (Giles and Pilkey 1965).

55. St. Catherines Island, which is located approximately 25 miles southwest of Tybee Island, has eroded continuously since 1858. The erosion occurring on this island is labeled "apparently natural" since no human activities (flood control, navigation improvements) are present. It is suggested that this erosion is mostly likely related to the fact that of all the Georgian barrier islands, St. Catherines is located the farthest distance from a major river.

PART IV: SUMMARY AND CONCLUSIONS

Erosion Protection Efforts

56. The history of erosion and erosion control efforts on Tybee Island provides a valuable lesson on the value of using shore processes data in the design of erosion control projects. Early erosion control projects at Tybee Island were based on numerous assumptions and a limited understanding of coastal processes. Also, little data were available for calculating the required structure strengths or evaluating the durability of construction material. The majority of the early project designs were based on the assumption that sand was eroded from the shore by southward-flowing longshore currents. This assumption resulted in the construction of groins to retard this movement. However, little regard was given to the potential offshore transport of sand and the gradual lowering of the beach elevation and width. Finally, little was known about the structural life of groins in the coastal environment. Although the art of coastal engineering design was just beginning to develop during the late 1800's and early 1900's, information was not readily available to the field. Shore protection structures designed during this period employed local engineering technology. Thus, many of these structures were inadequately designed.

57. With the advent of organizations such as the BEB and CERC, sources for state-of-the-art technology became available and design practices improved. The short lifespan of steel sheet pile bulkheads and groins led to the use of concrete sheet pile bulkheads and creosoted timber groins in the late 1930's and early 1940's. These structures were found to have a longer project life than their steel counterparts. When scouring and erosion near the concrete bulkhead threatened the structure on the northern portion of the island, quarrystone was successfully used for additional protection.

58. Most of the efforts to halt the recession of the shoreline used short groins to hold sediment on the beach. These attempts were generally unsuccessful, indicating that a single dominant longshore transport direction was not the only process contributing to the sediment budget. In the mid-1970's, the Corps of Engineers attempted to consider all of the sediment transport processes and sinks of eroded materials in the Tybee Island

project. The project had provisions for quantitatively monitoring and evaluating: (a) the effectiveness of the terminal groin as a sediment-retaining structure and (b) existing patterns of erosion and accretion. In previous projects no provisions were established for post-construction maintenance and evaluation. Data from the monitoring program, described in the GDM (Office, Chief of Engineers 1981) for the Tybee Erosion Control Project, were used in developing the design for rehabilitation of the original Erosion Control Project. In consideration of these data, the rehabilitation plan included modifications to existing groins, construction of additional groins, and a provision for renourishment.

Causes of Erosion

59. Among the many factors which should be considered when evaluating the erosional problems at Tybee Island are:

a. Location and orientation of the island with respect to the dominant wave energy.

b. Meteorological climate.

c. Characteristics of the littoral materials.

e. Impacts of previously constructed shore protection devices.

f. Rise in sea level.

g. The history of shoreline and offshore changes.

h. Effects which proposed actions will have on neighboring areas.

i. The effect of water levels and tidal currents.

60. This section briefly addresses these factors and how they might relate to Tybee. Erosional problems of the late 1800's were primarily confined to the northeast portion of Tybee Island (Figure 27a) which behaved very much like a headland, bearing the brunt of the attack by northeasterly high energy waves. Sediment transport from the northeast end was probably to the northwest and southwest. As this process continued, the beach became elongated, adjusting to an orientation which was less susceptible to erosion by waves from east and the northeast (Figures 27a,b,c, and d). Erosion along the island became more evenly distributed along the shoreface as indicated by (Figures 27b and c).

61. The geographic location and orientation of Tybee Island has probably been responsible for a portion of its shore erosion. The island is a headland

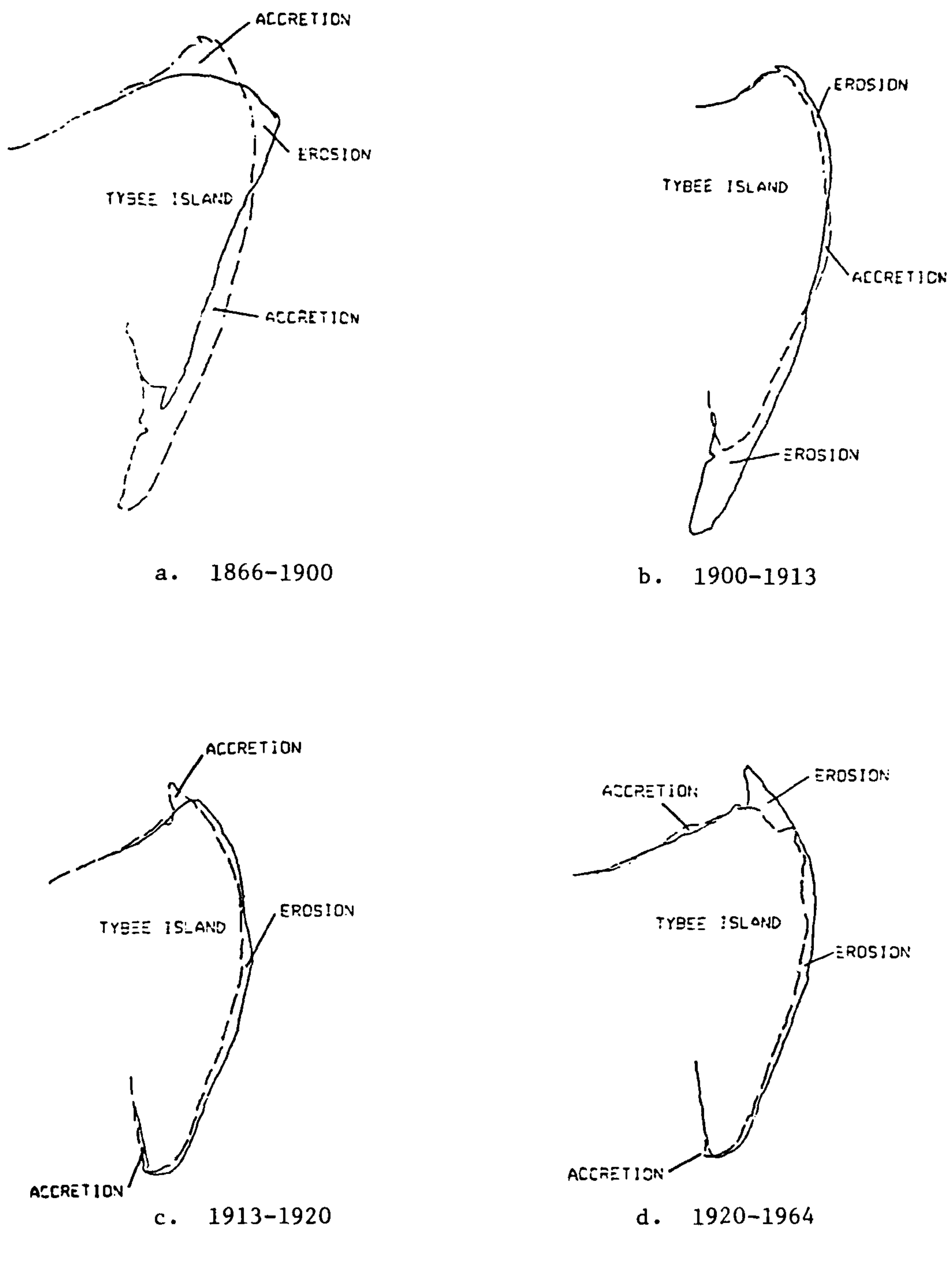


Figure 27. Shoreline locations of Tybee Island, 1866 to 1964

extending into the Atlantic Ocean and does not enjoy much protection. With the exception of the Gainors Bank submerged jetty, constructed in 1897, the northern portion of the island has little protection from approaching ocean waves (Figure 1). In contrast, the southern portion of the island is partially protected by offshore shoals which are shallow enough to cause shoaling and breaking of storm waves, thus reducing the nearshore wave energy climate (Figure 28).

62. Refraction diagrams for storm waves approaching from the east and northeast indicate that incoming wave energy is focused at the north end and on the shoals offshore of the southern end. The concentration of wave energy at the two ends of the island is accompanied by a decrease of wave energy along the central shoreline (Figure 26). This is probably one of the major reasons that the northern portion of Tybee Island has historically experienced severe erosion and the central portion has remained relatively stable.

63. Human interventions must also be considered in evaluating the erosion of Tybee Island. Erosion control works have been constructed on the island since the late 1800's when the first rock/timber groins were constructed to control erosion and enhance navigation in the Savannah River. Figure 17 summarized these attempts. Among those human actions which previously have and currently do impact on the natural shoreline processes of the Tybee Island are:

a. Renourishment of the beach.

b. Construction of groins, seawalls, and breakwaters on and near the island.

Among the human actions which may have impacted on the natural processes of sediment transport are:

a. Construction of the Savannah River navigational jetties.

b. Maintenance dredging operations on the Savannah River navigation channel.

c. Hydropower and flood control projects on the Savannah River.

d. Construction of housing and recreational facilities on and near the shoreline.

e. Changes in land usage along the Savannah River upstream of the harbor.

64. Although it is likely that all of the above actions impact on the natural sediment budget to some degree, the degree for each is difficult to quantify. Such a determination is not possible without extensive study.

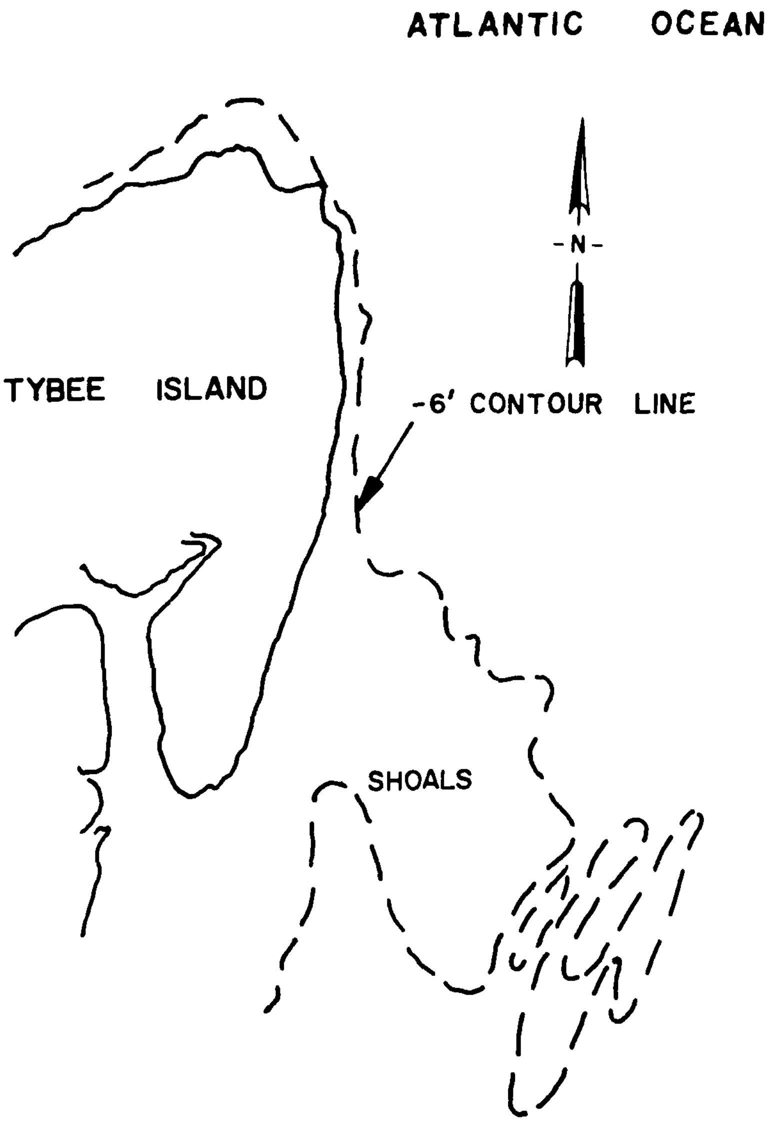


Figure 28. Location of shoal areas off the southern portion of Tybee Island

65. Approximately 6 months after the 1976 renourishment project the southern end of the island experienced unexpected severe erosion. Results of a study conducted in 1978 (Oertel 1978a, Posey and Seyle 1980) determined that a combination of three processes was responsible. According to the study, the three main processes causing accelerated erosion at the south end of the island were: (a) the concentration of wave energy at the south end of the island, (b) the seasonal production of wave-induced coastal currents flowing toward the Tybee Inlet throat, and (c) an asymmetrical tidal flow which produced a strong, flood-dominated channel adjacent to the south end of the island.

Present Status

66. In spite of the many attempts to control erosion along Tybee's shores, the loss of beaches continues to be a problem. The rapid loss of beachfill from the south end of the island in the late 1970's prompted the Savannah District to study the problem and develop a proposed rehabilitation plan. This plan was completed in 1981 and recommended placement of additional beachfill and construction of a terminal groin at the southern tip of the island (Office, Chief of Engineers 1981). This rehabilitation plan was submitted and approved for construction in 1982, but funding has not been authorized by the US Congress.

67. Since completion of the 1974-1976 nourishment project, several erosion control efforts by individuals and the local government have been employed to control localized erosion. These efforts have generally been in the form of rock fill and cinder block walls to augment the existing seawall. The seawall is in fair condition but has many sections which are in need of repair. The terminal groin at the northern end has settled but is still in good condition. The sand trapping ability of this structure continues to be suspect, as reported by Oertel (1978a). The 24 groins which exist along the oceanface are in various states of repair, ranging from dilapidated to fair (Figure 17).

68. In December 1983, the State of Georgia created a task force to study the Tybee Island problem and to develop recommendations for possible solutions. The present goal is to examine all available data and pertinent information and develop a plan by December 1984. The task force includes

members from the Georgia Geological Survey, the Savannah District, and several institutions of higher education.

Recommendations

69. Many factors must be considered in the design of erosion control systems and/or structures. Future studies at Tybee Island should first determine the causes of erosion and their relative significance. Then, most favorable corrective courses of action should be evaluated in terms of the processes they are trying to influence. Other factors which should be considered include:

a. Possible effects on Tybee Creek or other nearby channels.

b. Possible effects on neighboring shorelines.

c. Performance of previous erosion control efforts on Tybee Island or other similar areas.

d. Long-term trends of shoreline change in the Tybee Island area.

e. Costs.

70. Structural methods such as bulkheads and groins have been the most common form of erosion protection constructed on Tybee Island. Current practice often involves the use of beachfill in combination with structures as was the case with the 1976 project. Various selection criteria, as listed in Table 6, should be examined when deciding on appropriate structural measures (Office, Chief of Engineers 1981).

71. Serious consideration should be given to the use of dredged material from the Savannah Harbor navigation channel as beachfill. Should analyses of sediment samples indicate that the material is unsuitable for direct application to the beach face due to silt and clay content, it could possibly be placed in the nearshore area of the northern end of the island. This could create a man-made shoal which would (a) provide potential source material for littoral processes (which would also naturally cleanse the sediments) and (b) attenuate the energy of incoming waves. The feasibility and characteristics of such a shoal should be studied carefully with numerical techniques and other methods to insure that it would perform its intended function without causing undesirable side effects.

72. In some cases of shore erosion, offshore segmented breakwaters have been employed with highly satisfactory results (Pope and Rowen 1983, Lesnik

1979). When properly designed, offshore segmented breakwaters allow longshore drift to continue but at a reduced rate. A major advantage of such breakwaters is that the sediment is not deflected into deeper water and lost to the system, as frequently occurs with groins. The major disadvantage of these structures is that initial construction costs are greater than costs for land-based structures. Design criteria for offshore breakwaters are primarily based on refraction analyses to determine spacing, maximum storm conditions for structural design, and average wave climate for beach response (Pope and Rowen 1983, Toyoshima 1974).

73. An approach which should be considered (but often obtains little local support) concerns nonstructural methods. Among the nonstructural alternatives which might be considered for Tybee Island are:

<u>a</u>. Removal of threatened buildings next to the beach using funds slated for stabilization projects.

<u>b</u>. Establishment of setback lines and conservation easements to prevent further construction near the the beach.

74. A final nonstructural approach which is also usually unfavorable to local interests is the "do nothing" approach. This approach to public shoreline management is strongly supported by a growing number of coastal experts (Howard and Pilkey 1981). The general claim is that the rising sea level will force repeatedly bigger efforts of erosion control and result in greater and greater expenditure. The philosophy is simply to allow existing natural processes to seek equilibrium without human interference. An obvious drawback to this alternative would be the inevitable loss of private property in eroding areas.

75. Whatever courses of action are considered, it is important that the Tybee Island coast be considered as a single system. A reasonable sediment budget should be developed identifying the major sources and sinks as well as those processes which affect sediment distribution. Long- and short-term trends should be identified and the balance between onshore and offshore sediment movement should also be addressed. Any future action taken to alleviate erosion problems at Tybee Island should be documented by monitoring during and subsequent to construction. Although these factors are likely to be only partially understood, they must be considered in the selection of recommended "solutions." The history of shore protection efforts at Tybee and other islands documents the mistakes which can arise when solutions are employed which only address a local problem.

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AZIMUTH(DEGREES)= 0. -360.0
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PERIOD(SECONDS)

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0.50- 0.99	0	1368	522	1228	202	141	0	0	0	0	0	0	0	0	0	3459
1.00- 1.49	0	84	505	491	112	137	2	0	0	0	0	0	0	0	0	1331
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11.00-11.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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PERCENT OCCURRENCE(X 100) OF HEIGHT AND PERIOD BY DIRECTION
PERIOD(SECONDS)

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8.00- 8.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.50- 8.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.00- 9.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.50- 9.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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10.50-10.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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12.50-12.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.00-13.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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14.50-14.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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AZIMUTH(DEGREES)= 0. -360.0
PERCENT OCCURRENCE(X 100) OF HEIGHT AND PERIOD BY DIRECTION
PERIOD(SECONDS)

HEIGHT(METERS)	0. - 2.99	3.00- 4.99	5.00- 6.99	7.00- 8.99	9.00- 10.99	11.00- 12.99	13.00- 14.99	15.00- 16.99	17.00- 18.99	19.00- 20.99	21.00- 22.99	23.00- 24.99	25.00- 26.99	27.00- 28.99	29.00- 30.99	TOTAL
0.01- 0.49	1569	2846	958	108	0	0	0	0	0	0	0	0	0	0	0	5481
0.50- 0.99	0	1555	798	88	0	0	0	0	0	0	0	0	0	0	0	2441
1.00- 1.49	0	6	484	114	0	0	0	0	0	0	0	0	0	0	0	604
1.50- 1.99	0	0	67	184	1	0	0	0	0	0	0	0	0	0	0	252
2.00- 2.49	0	0	15	124	2	0	0	0	0	0	0	0	0	0	0	141
2.50- 2.99	0	0	0	31	6	0	0	0	0	0	0	0	0	0	0	37
3.00- 3.49	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	4
3.50- 3.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.00- 4.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4.50- 4.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.00- 5.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5.50- 5.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.00- 6.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6.50- 6.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.00- 7.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7.50- 7.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.00- 8.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8.50- 8.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.00- 9.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.50- 9.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.00-10.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.50-10.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.00-11.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11.50-11.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.00-12.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12.50-12.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.00-13.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.50-13.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.00-14.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.50-14.99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	1569	4407	2322	649	13	0	0	0	0	0	0	0	0	0	0	

CALM = 10.00 PERCENT

1. This Appendix contains wave data, including height, period, and direction, based on hindcast calculations using meteorological data from 1956-1975. Tables and figures were generated using SEAS. The following descriptions of the wave data, tables and figures in this appendix are adapted from Ragsdale (1983).*

2. Sea and swell significant wave data (height, period, and direction) are taken directly from the SEAS data base. Combined wave significant data are computed from these sea and swell data where: (a) height is equal to the square root of the sum of squares of sea and swell wave height, (b) period is that of the dominant wave (sea or swell), and (c) direction is that of the dominant wave.

3. Percentages in the tables are multiplied by 100 to display greater precision. Thus a table value of 967 is 9.67 percent for that particular combination of wave height and period. In addition, percentage frequencies, multiplied by 100, are tabled at the right side of the figure for each height category.

4. Tables A1-A3 are tabular grids of percent occurrence of significant waves in height and period ranges by direction. Height is presented in columnar format while period is presented in row order. The table includes all possible wave direction (0.0 to 360.0 deg azimuth).

5. Figures A1 and A2 are vertical histogram/barcharts of the percent occurrence of significant wave height at predefined intervals. Percentages are graduated along the y-axis from 0 through 50 percent in 1 percent increments. The x-axis reflects significant wave height and is graduated from 0 through 15 metres, in 1-metre increments. Frequency counts are also displayed below the x-axis for each height interval.

6. There is a marked similarity between Figures A1-A6, with the only difference being that Figures A1 and A2 display wave height, Figures A3 and A4 display wave period, and Figures A5 and A6 display wave direction of origin.

* References are located at the end of the main text.

APPENDIX A: SUMMARY OF WAVE DATA FROM SEA-STATE ENGINEERING ANALYSIS SYSTEM (SEAS)

Table 6

Criteria for Selecting Coastal Structures

	Type of Structure				
	Bulkheads*	Seawalls*	Revetments*	Groins*	Protected Beaches*
		Functions			
Applicability to small projects	Yes	Yes	Yes	No**	No
Recreational beach provision	No	No	No	Limited unless filled	Yes
Backshore† erosion prevent	Yes (secondary)	Yes	Yes	No, unless filled	Yes††
Backshore wave protection	Yes (secondary)	Yes	Limited if filled	No	Limited
Backshore slope retention	Yes (secondary)	Yes	Limited	No	No
		Effects of Environmental Conditions			
Beach profile with flat backshore slope	Negates earth retaining function	Negates secondary earth retaining function	None	None	None
Beach profile with steep backshore slope	Usual condition for earth re-taining function	Earth retaining capability may be exceeded	Bank may need to be graded	None	None
Beach profile with flat foreshore‡ slope	None	None	None	Longer length structure required	Lower fill volume required
Beach profile with steep foreshore slope	Larger waves with more force could reach this structure			Higher structure required	Higher fill volume required
Waves	Size and strength of structures are dependent on wave height Reflected waves cause beach erosion				Steep‡‡ waves erode; flat§ waves help maintain
Longshore sand movements	None	None	None	Provides fill for trapping. High volume required for success	Longshore currents distribute fill along shores
Windblown sand	None	None	None	Provides fill for trapping	None

* Adapted from notes contained in US Army Engineers Coastal Engineering Technical Notebook.
** In some cases a single structure may suffice, but usually a series of groins are required.
† That upper zone of the beach which is acted upon only during severe storms.
†† Provided periodic renourishment is maintained.
‡ That part of the shore that is ordinarily exposed to the uprush and backrush of wave action as the tides rise and fall.
‡‡ Distance between successive crests are 10 to 20 times their height.
§ Distance between successive crests are 30 or more times their height.

Table 5

Percent Change in Total Nourishment Volume and Percent of Original Volume Remaining in Six Sections of the Beach

	Volume Placed		Percent Remaining				Aug 77 Volume	Percent Change	
Location	1000 yd^3	Percent	May 76	Aug 76	Feb 77	Aug 77	1000 yd^3	of Total	Description
TG-6	170.91	(7.6)	112	116	111	124	211.83	+1.8	Accretion
6-8	410.23	(18.1)	88	81	73	72	293.66	-5.1	Erosion
8-10	355.96	(15.7)	97	87	100	97	354.96	-0.4	Stable
10-14	683.44	(30.2)	97	93	86	82	559.57	-5.5	Erosion
14-17	401.25	(17.7)	109	109	111	112	448.23	+2.1	Accretion
17-END	239.73	(10.6)	74	57	54	22	51.62	-8.3	Erosion
TOTAL	2,262.00	(99.9)	96	91	88	85	1,910.87	-15.4	Erosion

(Adapted from Oertel 1978c)

*TG is terminal groin; other numbers refer to streets.

Table 4

Changes in the Beach Project Area Between April 1976 And February 1978

Location	Area of Beach Added by Nourishment (April 1976)		Remaining Area of Nourished Beach (February 1978)		Percent Change -lost +gained
	square feet	acres	square feet	acres	
Terminal groin to Transect A	739,212	17.0	669,034	15.4	-9.4
Transect A to Transect B	669,034	15.4	463,177	10.6	-30.8
Transect B to First Street	481,892	11.1	411,713	9.5	-14.4
First St. to Third St.	364,928	8.4	290,071	6.7	-20.2
Third St. to Sixth St.	336,856	7.7	407,035	9.3	+20.8
Sixth St. to Ninth St.	257,321	5.9	318,142	7.3	+23.7
Ninth St. to Twelfth St.	290,071	6.7	341,535	7.8	+17.7
Twelfth St. to Fourteenth St.	201,178	4.6	159,071	3.7	-20.9
Fourteenth St. to Sixteenth St.	145,035	3.3	51,464	1.2	-64.5
Sixteenth St. to Eighteenth St.	65,500	1.5	-70,178*	-1.6	-207.1
Total	3,551,026	81.6	3,041,064	69.8	-14.4

*The minus values indicate that in this area all of the nourished beach material (65,500 sq ft or 1.5 acres) had been eroded, as well as 70,178 sq ft (1.6 acres) of beach which existed before the nourishment program began.

(Adapted from Zisa 1978)

Table 3

Summary of Neutrally Buoyant Current Drifter Study at Tybee Creek Delta

October 16, 1978 FLOOD TIDE

Run No.*	Start Time (EDT)	Tide Gage ft, MLW	Elapsed Time Sec	Distance ft	Average Velocity fps	Maximum Velocity fps	Maximum Velocity Directions		Minimum Velocity fps	Minimum Velocity Direction	
1	1612	0.9	120	TEST	-	-	-		-	-	
2	1625	1.2	120	TEST	-	-	-		-	-	
3	1632	1.7	960	1435	1.49	2.50	258	WSW	0.83	269	WSW 277
WNW											
4	1656	2.5	1200	820	0.68	1.17	245	WSW	0.25	255	WSW
5	1722	2.5	1440	515	0.36	0.67	285	WNW	0.17	252	WSW
6	1749	4.4	1020	1540	1.51	2.50	252	WSW	0.75	252	WSW
7	1812	5.2	780	1570	2.01	3.58	297	WNW	1.00	222	SSW
8	1833	5.9	1200	2015	1.68	3.58	264	WSW	0.83	233	WSW
Average 4 & 5	1656	2.5	1320	668	0.52	0.92	265	WSW	0.21	254	WSW
Average 3,6,7,8	1632	4.3	990	1640	1.67	3.04	268	WSW	0.85	244	WSW

*Refer to Figure 23b for run number locations.

(Adapted from Oertel 1979b)

Table 2

Flow Volume Data at Tybee Creek Entrance*

(Million Cubic Feet)

Time (EDT)	South Channel (4)**	Center Channel (8)	Bar	North Channel (6)	Total Vol	Little Tybee Island Marsh	Trib Creek & Marsh	Tybee Creek (1)-(2)-(3)
1400-1455	0.3	0.8	0.5	0.1	1.7	0.6	1.0	0.1
1455-1600	5.4	30.2	0.0	7.5	43.1	2.2	14.6	26.3
1600-1700	18.3	55.8	2.1	21.3	97.5	0	23.8	73.7
1700-1800	41.4	80.0	3.8	34.1	159.3	0	44.1	115.2
1800-1900	55.5	80.4	8.9	52.6	197.4	0	43.2	154.2
1900-2000	65.6	65.9	13.9	62.5	207.9	0	18.4	189.5
2000-2100	72.7	50.7	9.3	43.1	175.8	0	25.0	150.8
2100-2140	26.7	9.7	0.0	8.3	44.7	0.8	19.5	24.4
2140-2200	7.4	9.3	8.8	3.9	29.4	0.0	4.6	24.8
2200-2300	103.5	69.8	0	18.9	192.2	5.0	39.1	148.1
2300-2400	130.0	125.6	0	19.8	275.4	7.7	60.9	206.8
2400-0100	78.9	124.1	0	27.5	230.5	5.8	58.8	165.9
0100-0200	23.5	77.0	0.1	25.9	126.5	1.0	42.0	83.5
0200-0300	2.3	39.1	0	12.2	55.6	3.2	18.4	32.0
0300-0320	0.1	0.8	0	0.3	1.2	0.0	0.1	1.1
Total flood	285.9	373.5	38.5	229.5	927.4	3.6	189.6	734.2
percent	31	40	4	25	100	-	-	-
Ebb	345.1	445.7	8.9	108.5	908.8	22.7	223.9	662.2
percent	38	49	1	12	100	-	-	-

* Office, Chief of Engineers (1981).

** Refer to Figure 22 for corresponding locations.

Table 1

Notable Hurricanes Experienced At Tybee Island, 1854 to 1983*

Date	Classification**	Deaths†	Winds††
Sep 7-12, 1854	Hurricane	Unknown	90
Aug 21-26, 1885	Extreme	22	125
Aug 15-Sep 2, 1883	Great	1000-2000	96
Sep 18-30, 1984	Hurricane	4	104
Sep 22-29, 1896	Hurricane	116	80
Sep 25-Oct 6, 1898	Extreme	179	-
Oct 9-23, 1910	Great	30	125
Aug 23-30, 1911	Major	25	106
Aug 5-15, 1940	Major	34	73
Oct 12-23, 1944	Great	18	120
Sep 11-20, 1945	Great	26	170
Oct 9-16, 1947	Hurricane	1	95
Sep 20-Oct 2, 1959	Major	22	150
Jun 4-14, 1966	Major	6	125

* Compiled from data contained in Monthly Weather Review (Sugg, Pardue, and Carrodus 1977 and Ludlum 1963).

** Classification of hurricane intensity as determined by barometric pressure and windspeed: Order of intensity: Most intense-----Extreme
Great
Major
Least intense----Hurricane

† Number of deaths is not for Tybee Island but is the total number of deaths attributed to each hurricane.

†† Maximum recorded windspeeds in mph at some point along the hurricane's path.

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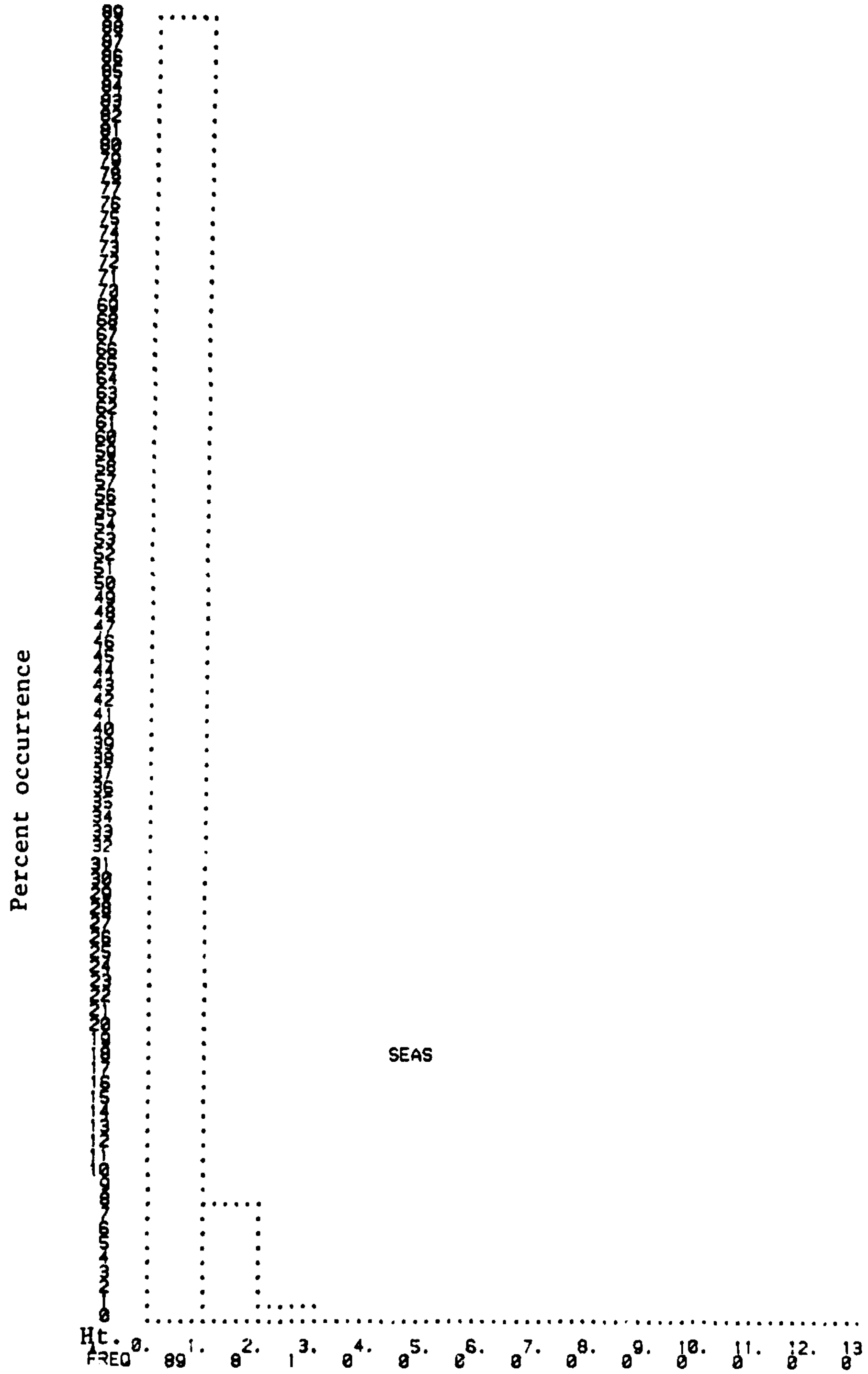


Figure A1. Histogram of wave height (sea only)

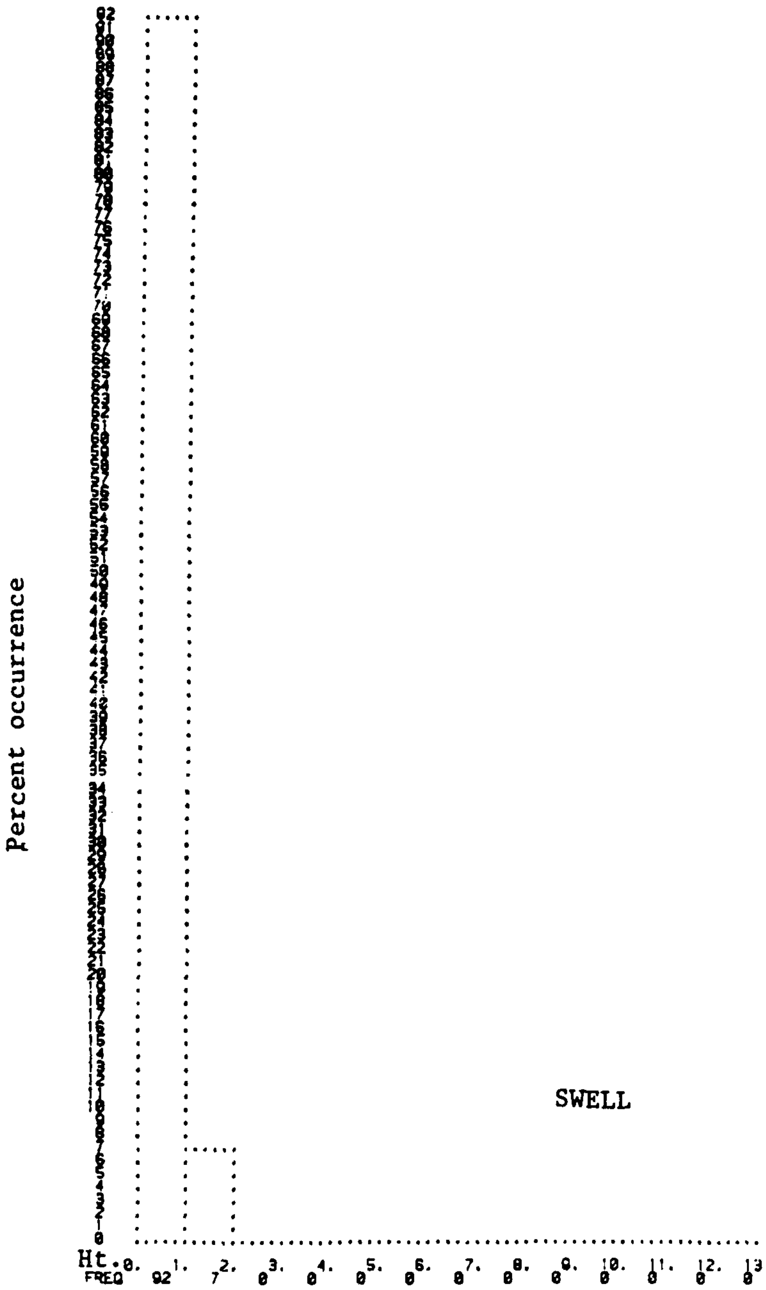
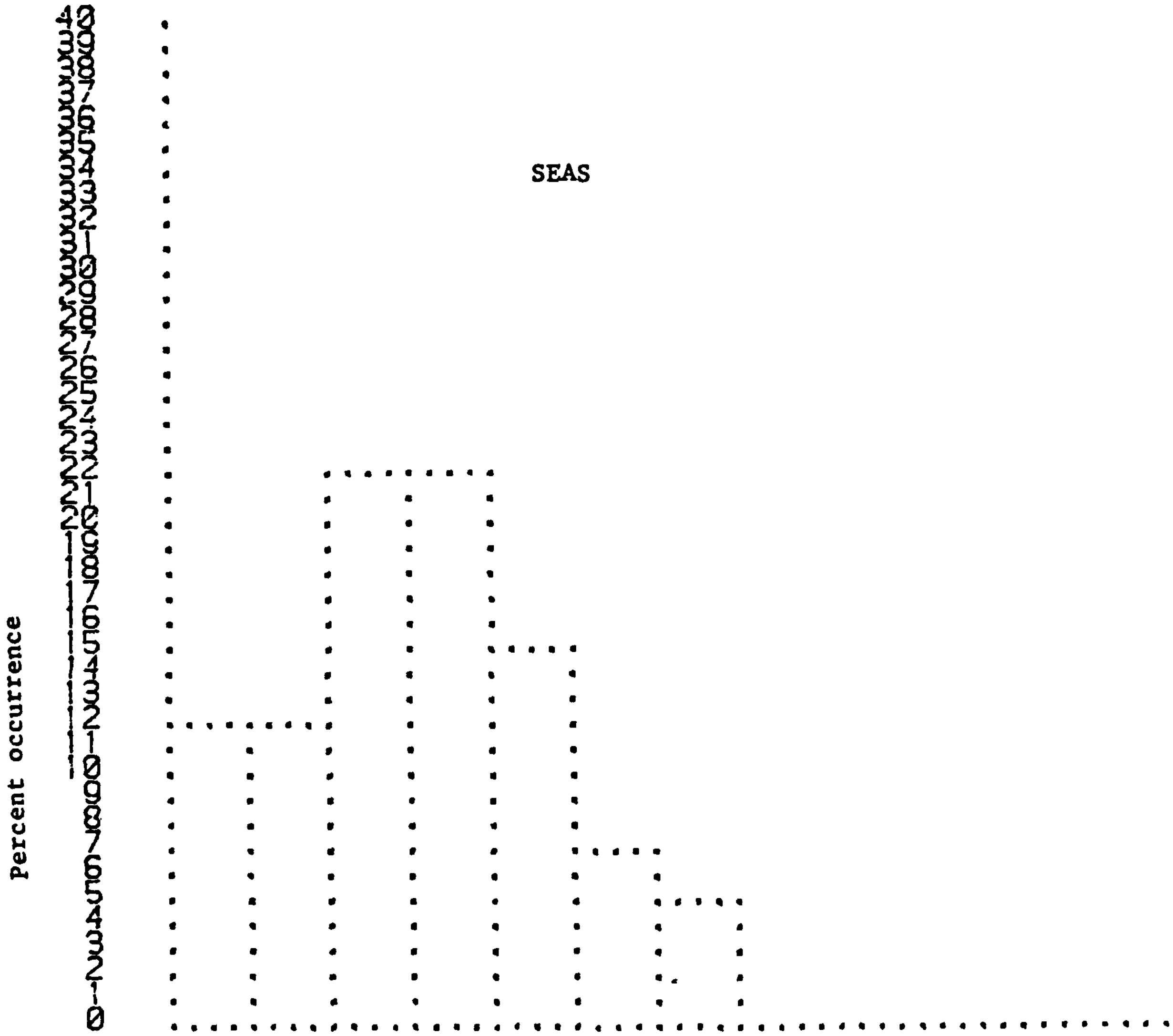


Figure A2. Histogram of wave height (swell only)



PERIOD, SECONDS

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
FREQ	12	12	22	22	15	7	5	0	0	0	0	0	

Figure A3. Histogram of wave period (sea only)

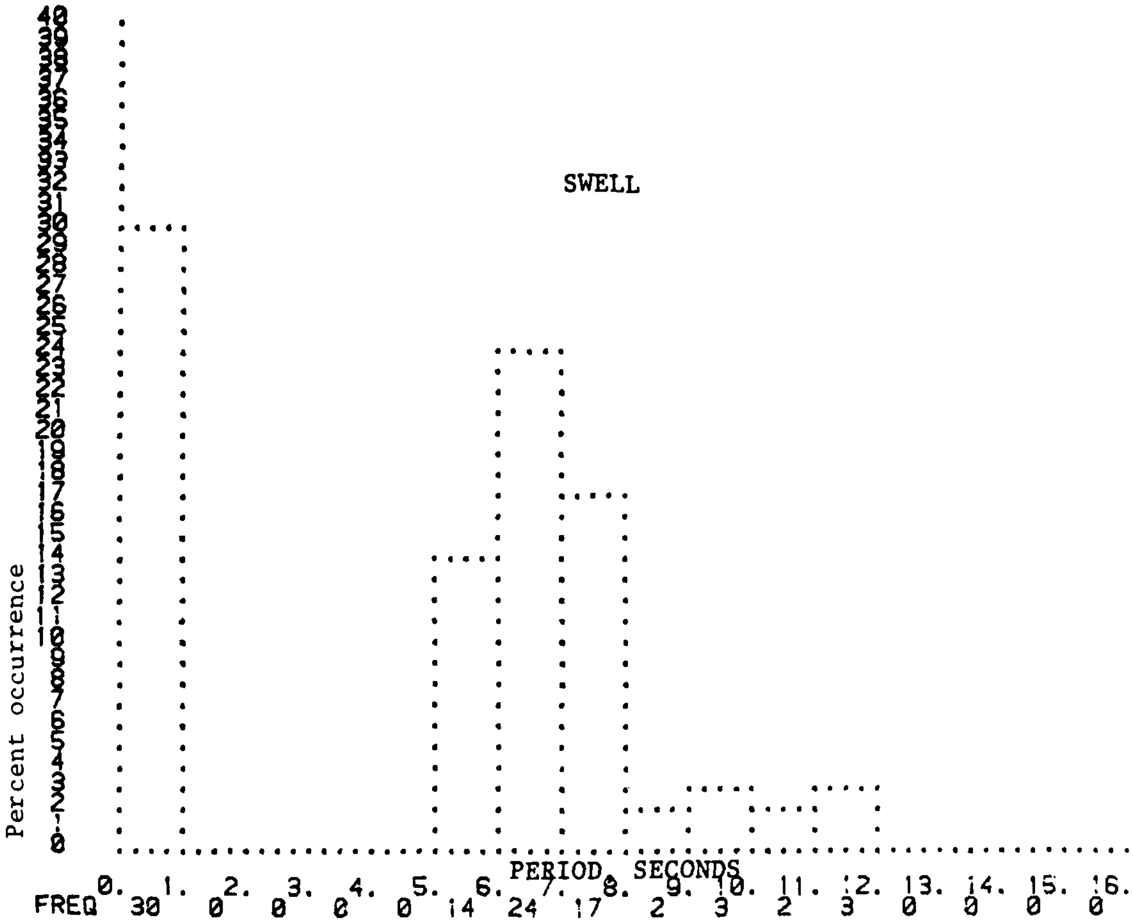


Figure A4. Histogram of wave period (swell only)

Figure A5. Histogram of wave direction of origin

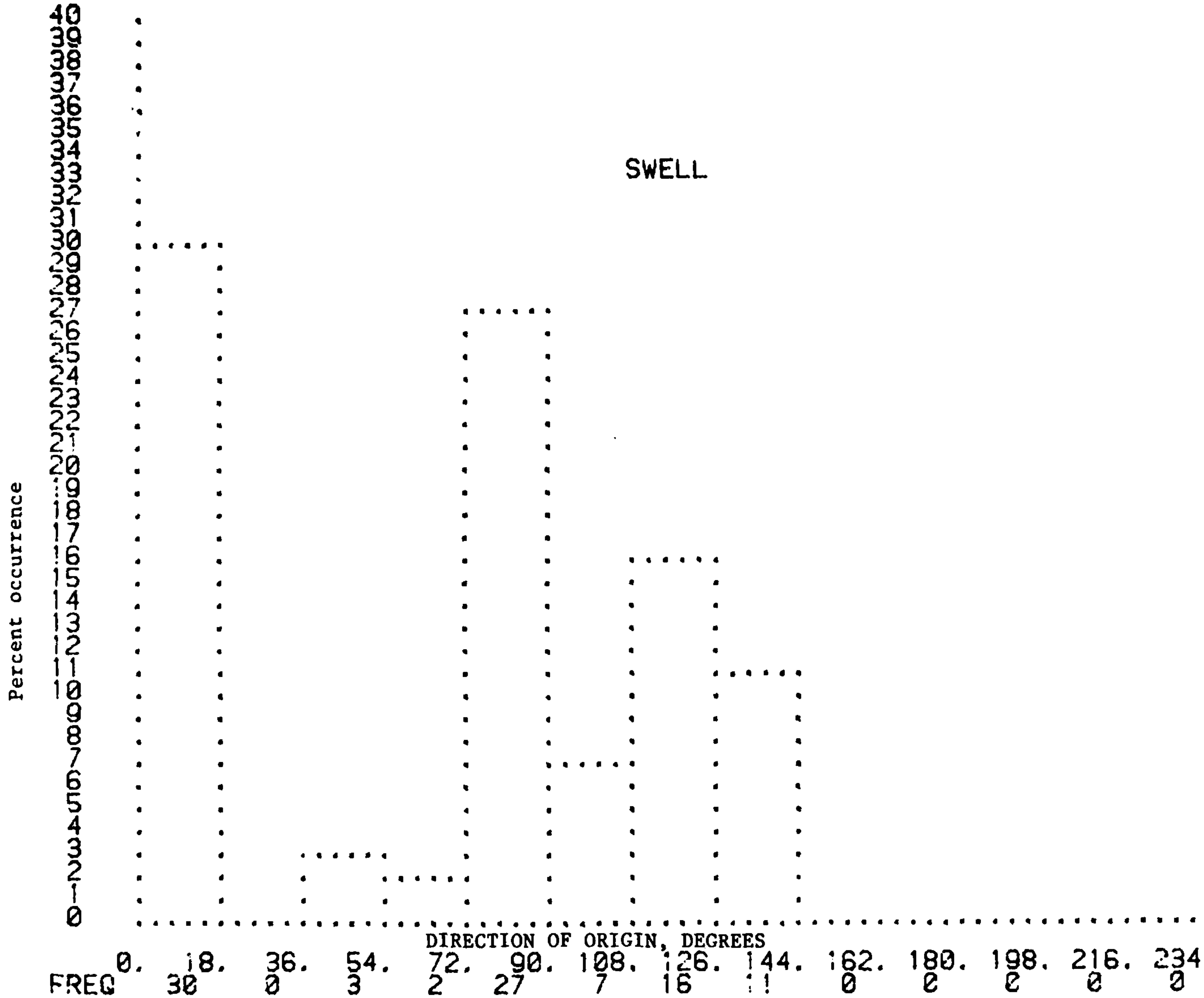
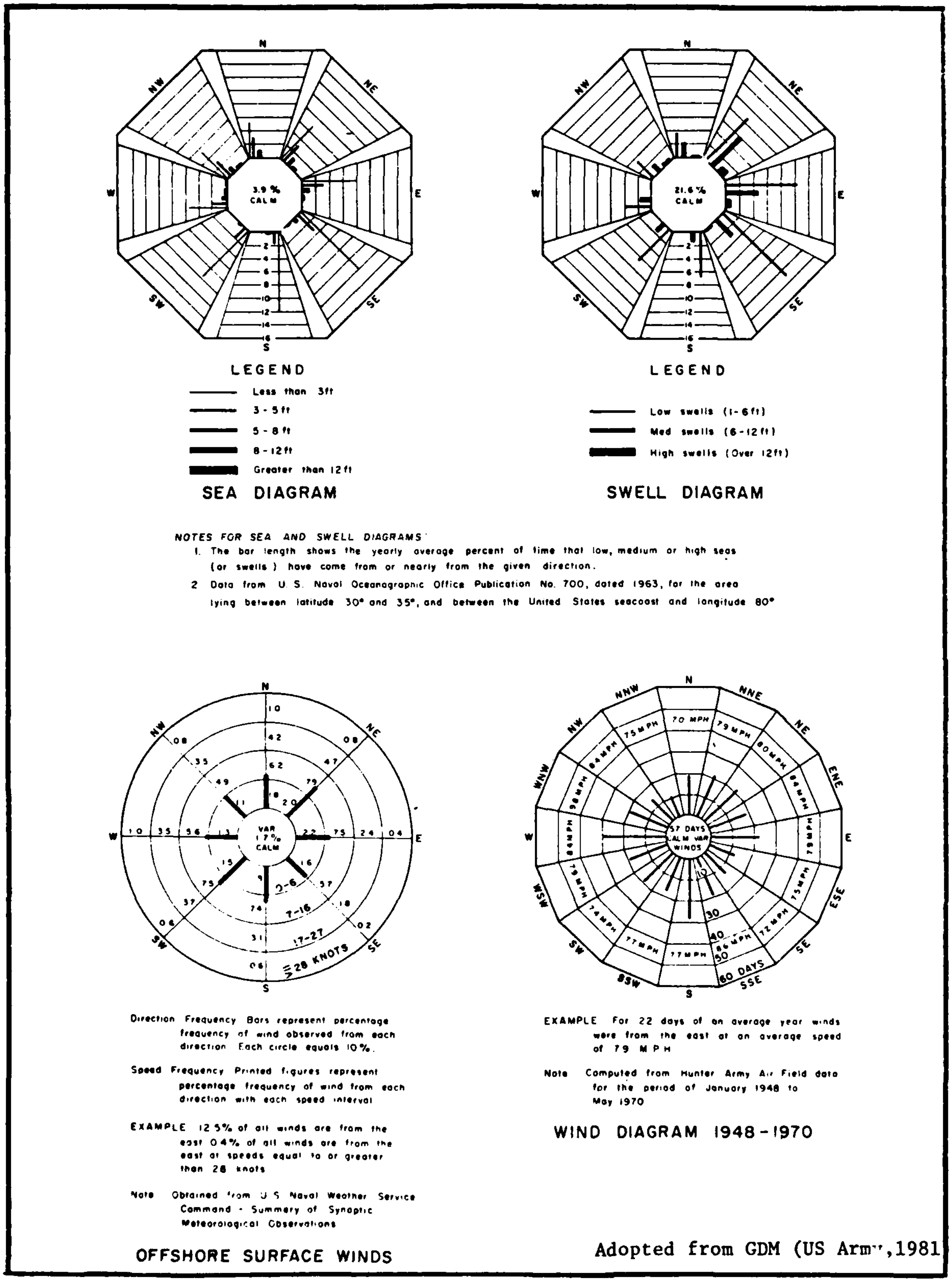


Figure A6. Histogram of wave direction of origin



Adopted from GDM (US Arm",1981

Figure A7. Wind and wave information. (Office, Chief of Engineers 1981)

APPENDIX B: CALCULATIONS FOR STORM SURGE AT TYBEE ISLAND

TIDAL RANGE AT TYBEE : 6.8 FT

MAX SPRING TIDE RANGE : 9.0 FT

WIND SET-UP: 2-3 FT

PARAMETERS FOR HURRICANE CAMILLE:

ΔP = 3.19 IN. MERCURY = 108.0 MBARS

V_F = 13.00 KNOTS/HR = 14.5 MPH

R = 14.00 NAUTICAL MILES = 15.6 MILES

FROM FIG. 3-51 , SPM S_I = 22.0 FT MSL

FROM FIG. 3-53 , SPM F = 1.3 (SHOALING FACTOR)

CORRECTION FOR STORM MOTION --> MAX = 1.03 AT 15.6 MPH

S_P = 22.0 (1.3) (1.03) = 29.5 FT ABOVE MSL

Figure B1. Calculations based on 1977 Shore Protection Manual method to predict storm surge which would be caused by a hurricane equivalent to Camille (US Army Engineer Coastal Engineering Research Center 1977)

APPENDIX C: NATIONAL COAST SURVEY CHARTS OF TYBEE ISLAND

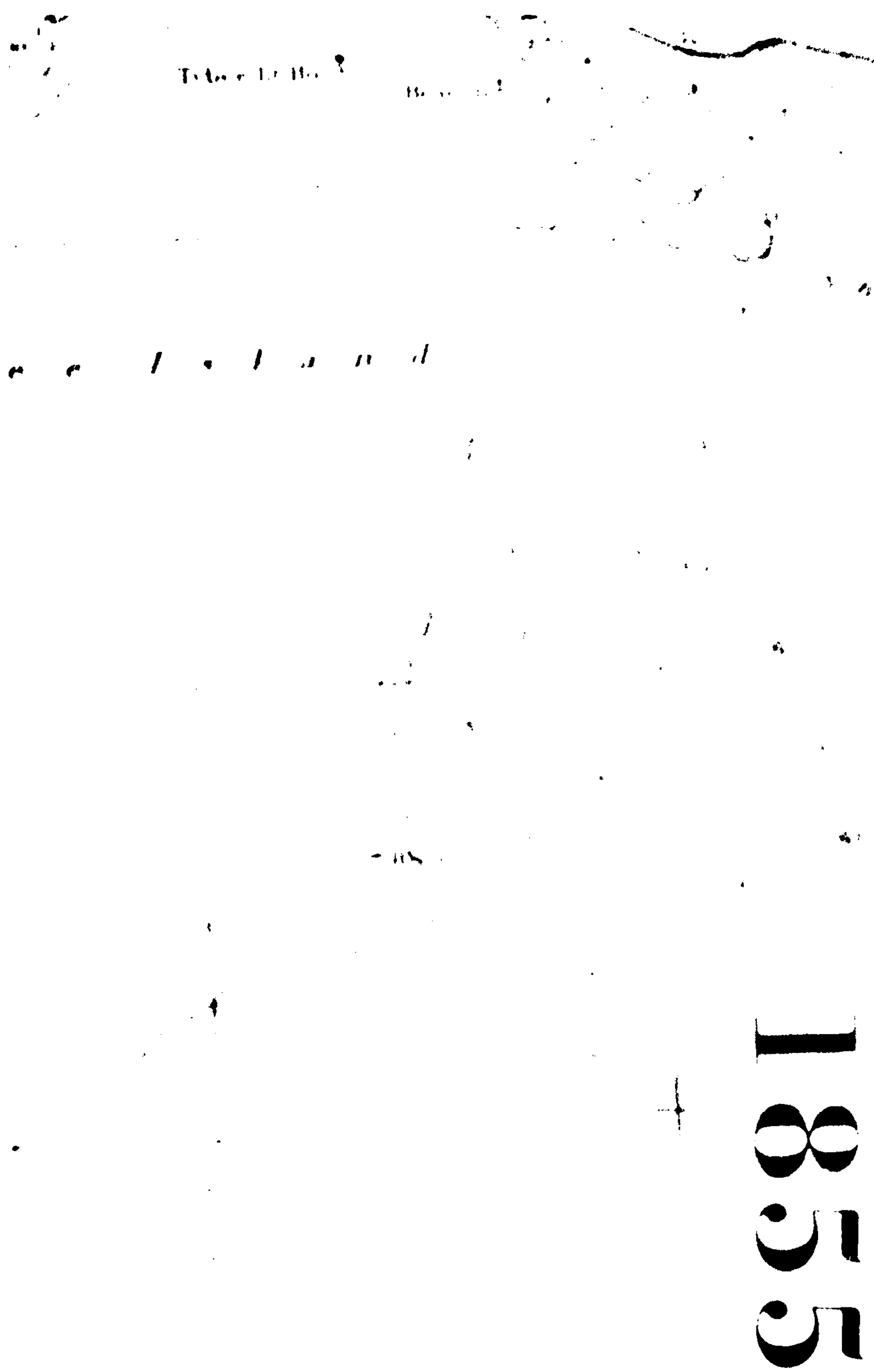


Figure C1. National Coast Survey Chart, 1855

Figure C2. National Coast Survey Chart, 1866

Figure C3. National Coast Survey Chart, 1867

Figure C4. National Coast Survey Chart, 1875

AD-A156 163 HISTORY OF EROSION AND EROSION CONTROL EFFORTS AT TYBEE ISLAND GEORGIA(U) COASTAL ENGINEERING RESEARCH CENTER VICKSBURG MS G F OERTEL ET AL. FEB 85 CERC-85-1 2/2

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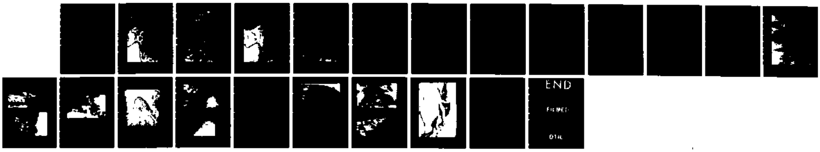

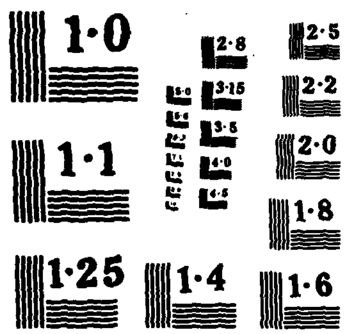

NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

Figure C5. National Coast Survey Chart, 1896

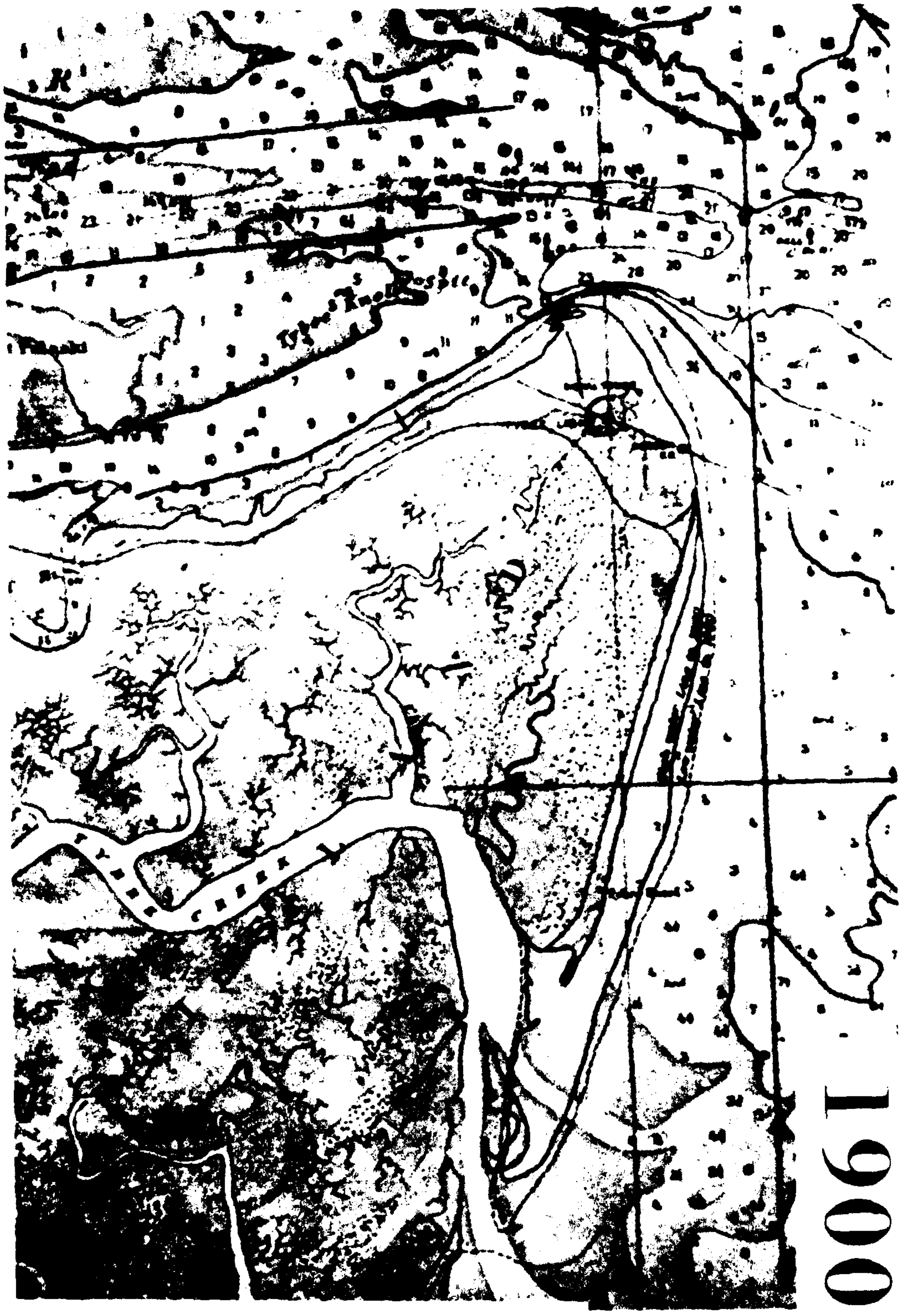

Figure C6. National Coast Survey Chart, 1900

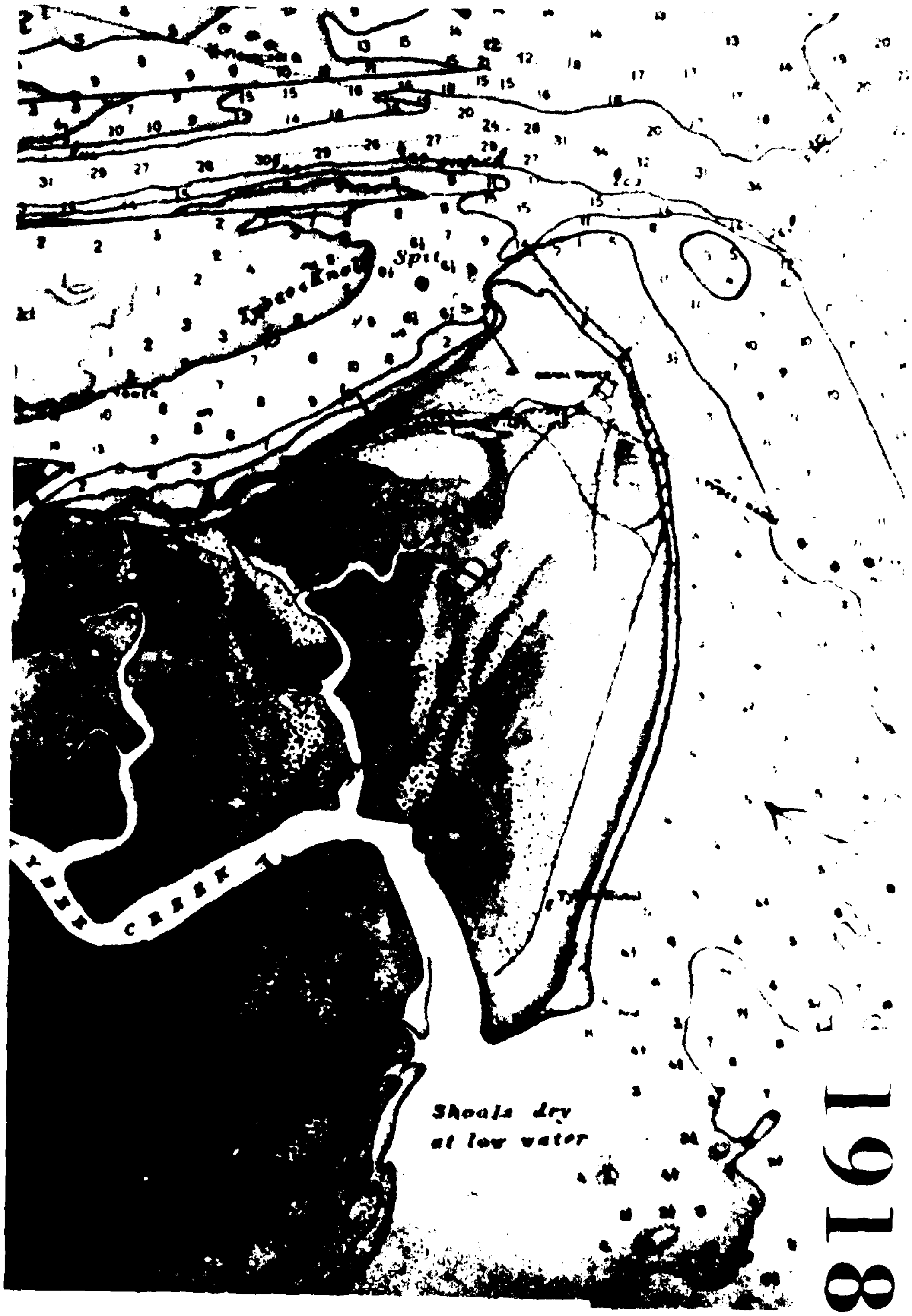

Figure C7. National Coast Survey Chart, 1918

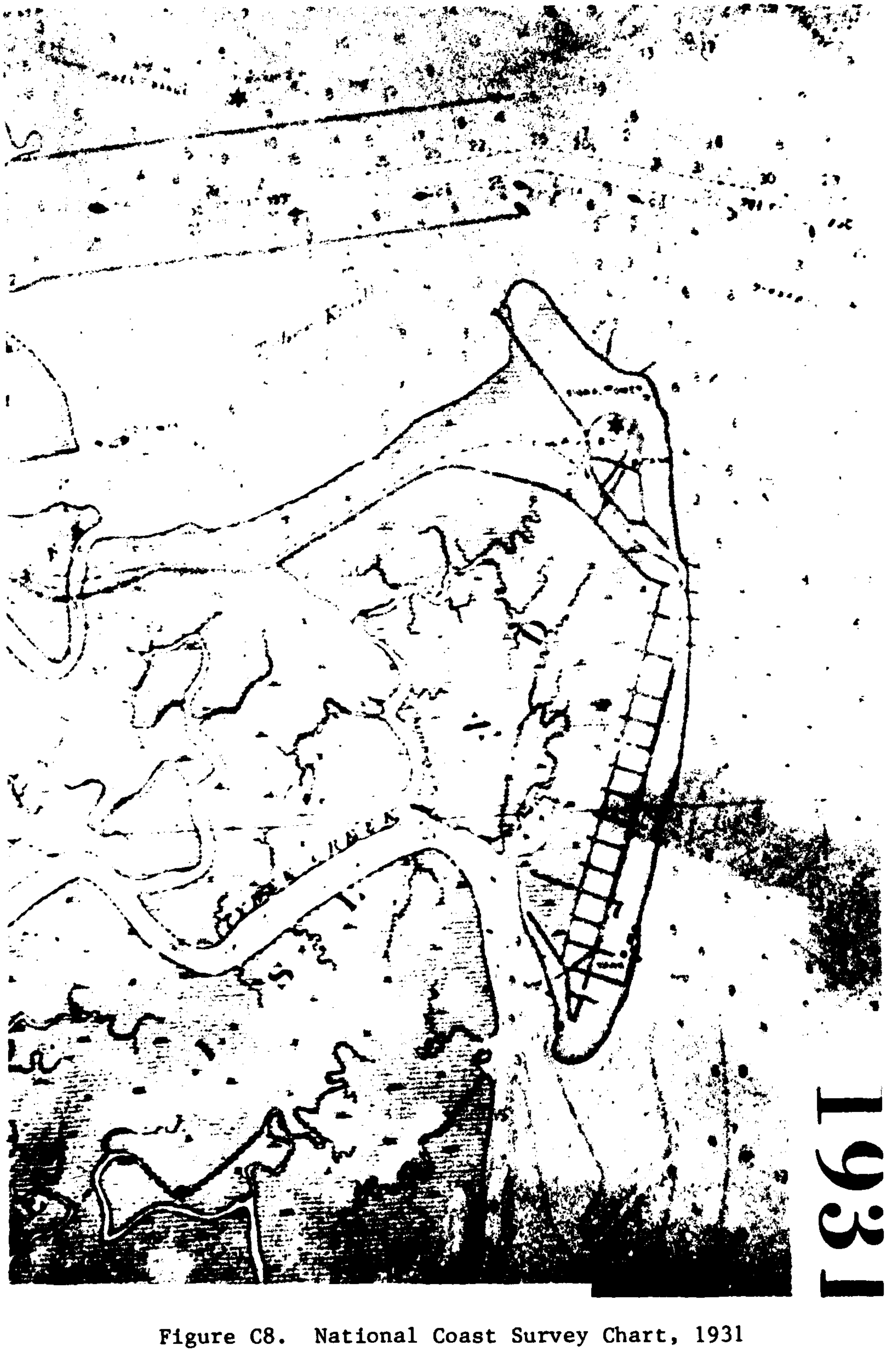

Figure C8. National Coast Survey Chart, 1931

APPENDIX D: REFRACTION DIAGRAMS FOR VARIOUS WAVE CONDITIONS OFF TYBEE ISLAND

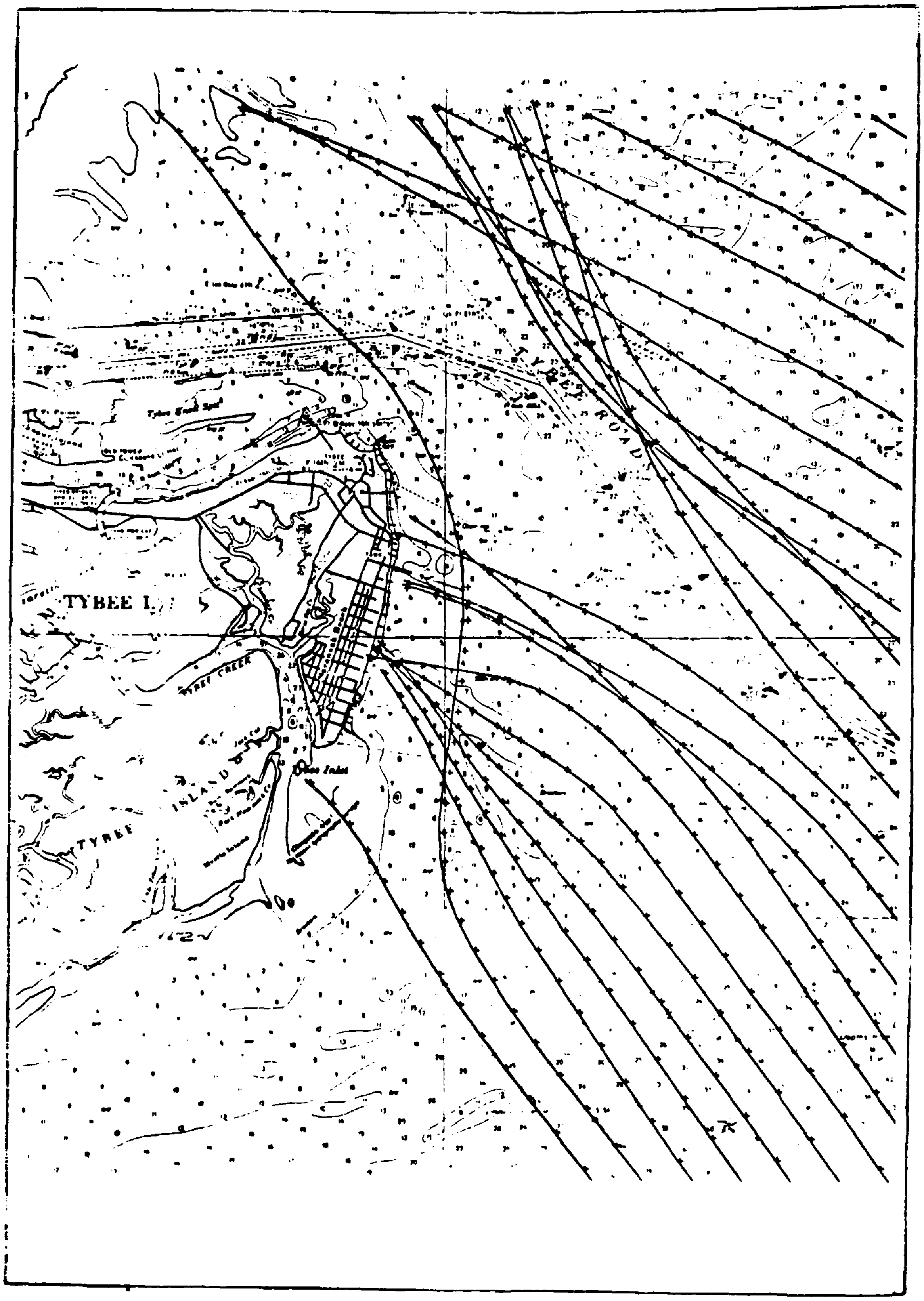

Figure D1. Refraction diagram with H = 2.0 ft, T = 8.5 sec, and $\alpha = 145^{\circ}$

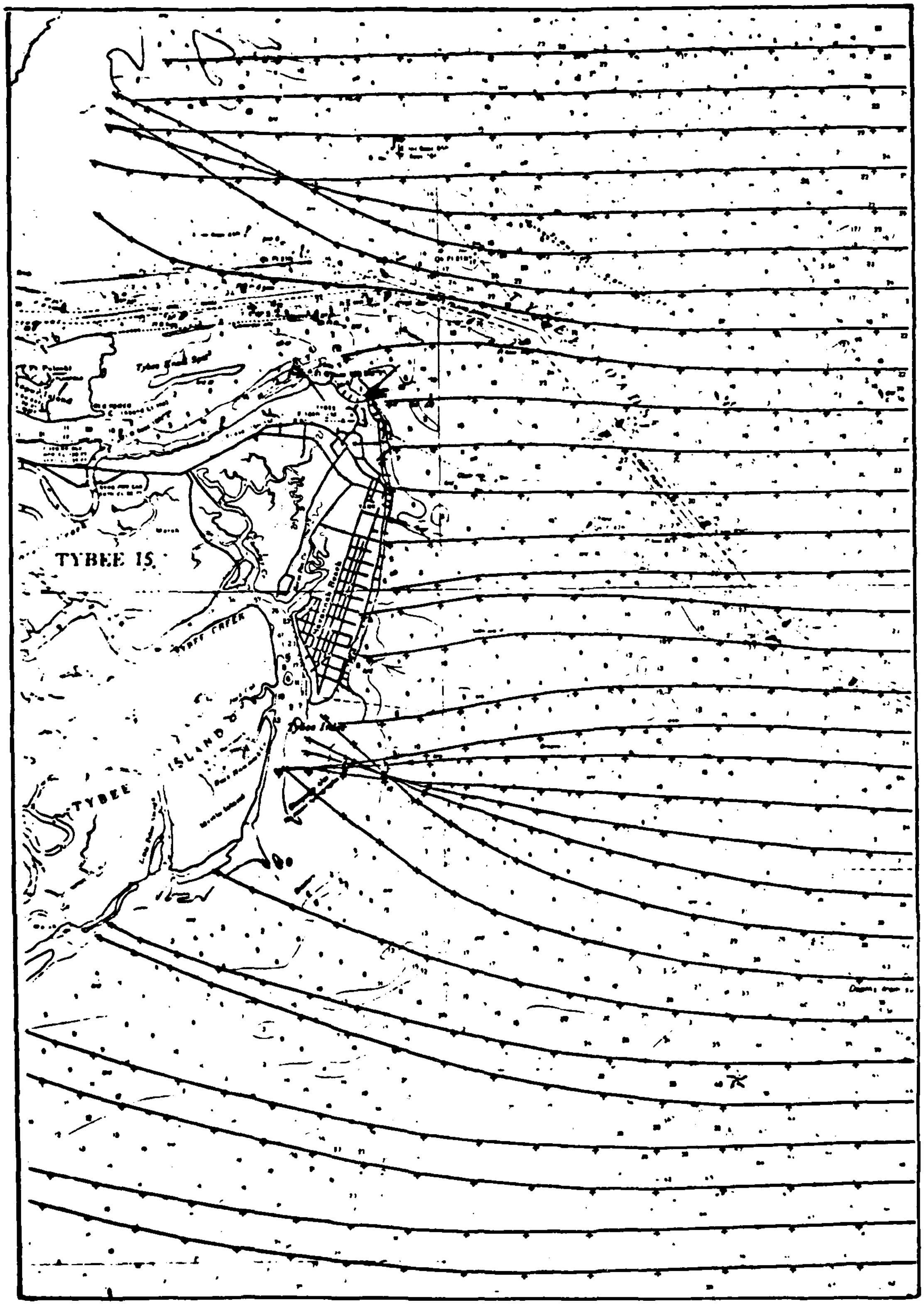

Figure D2. Refraction diagram with H = 5.5 ft, T = 6.5 sec, and α = 89°

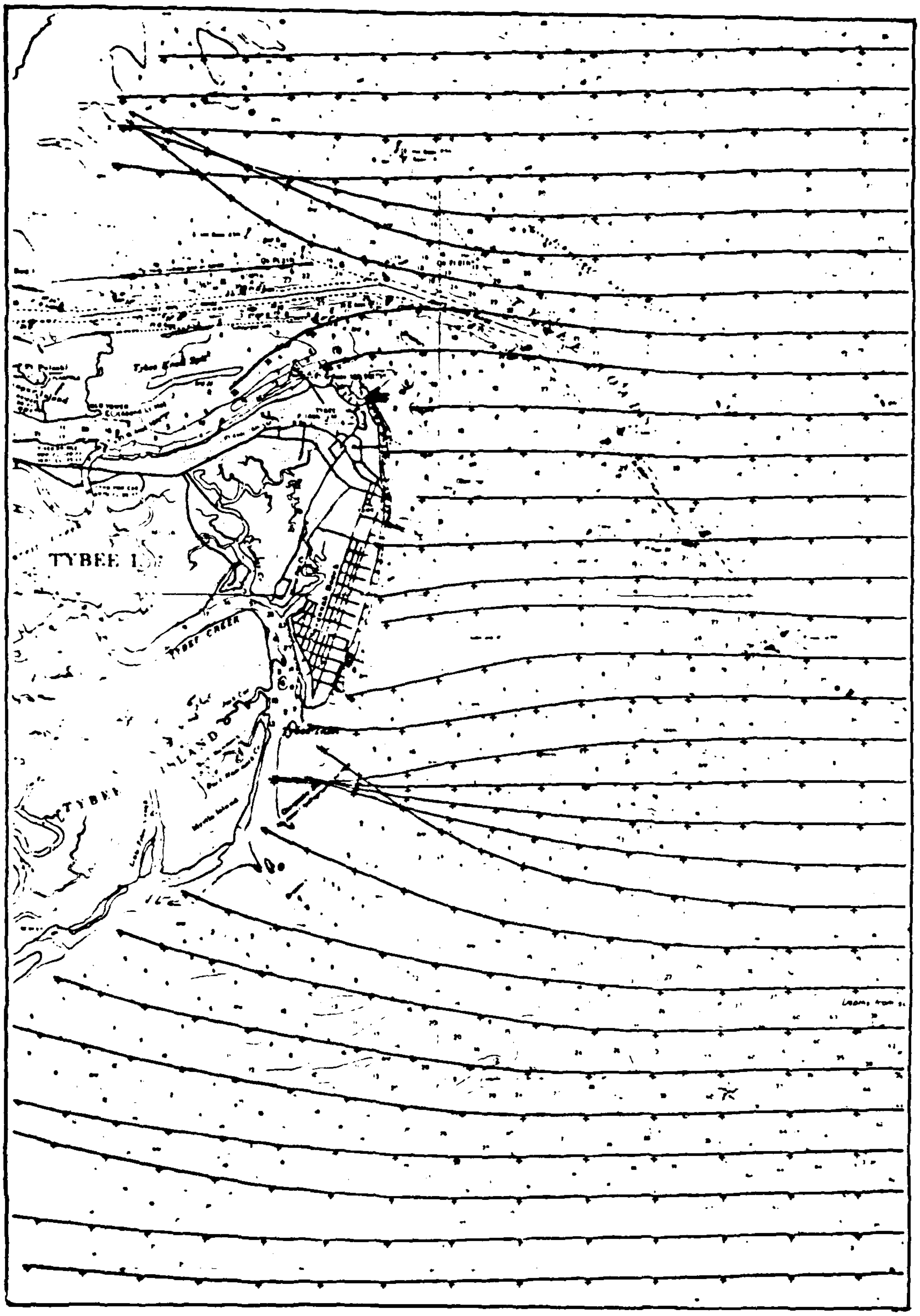

Figure D3. Refraction diagram with $H = 4.5$ ft, $T = 5.5$ sec, and $\alpha = 89°$

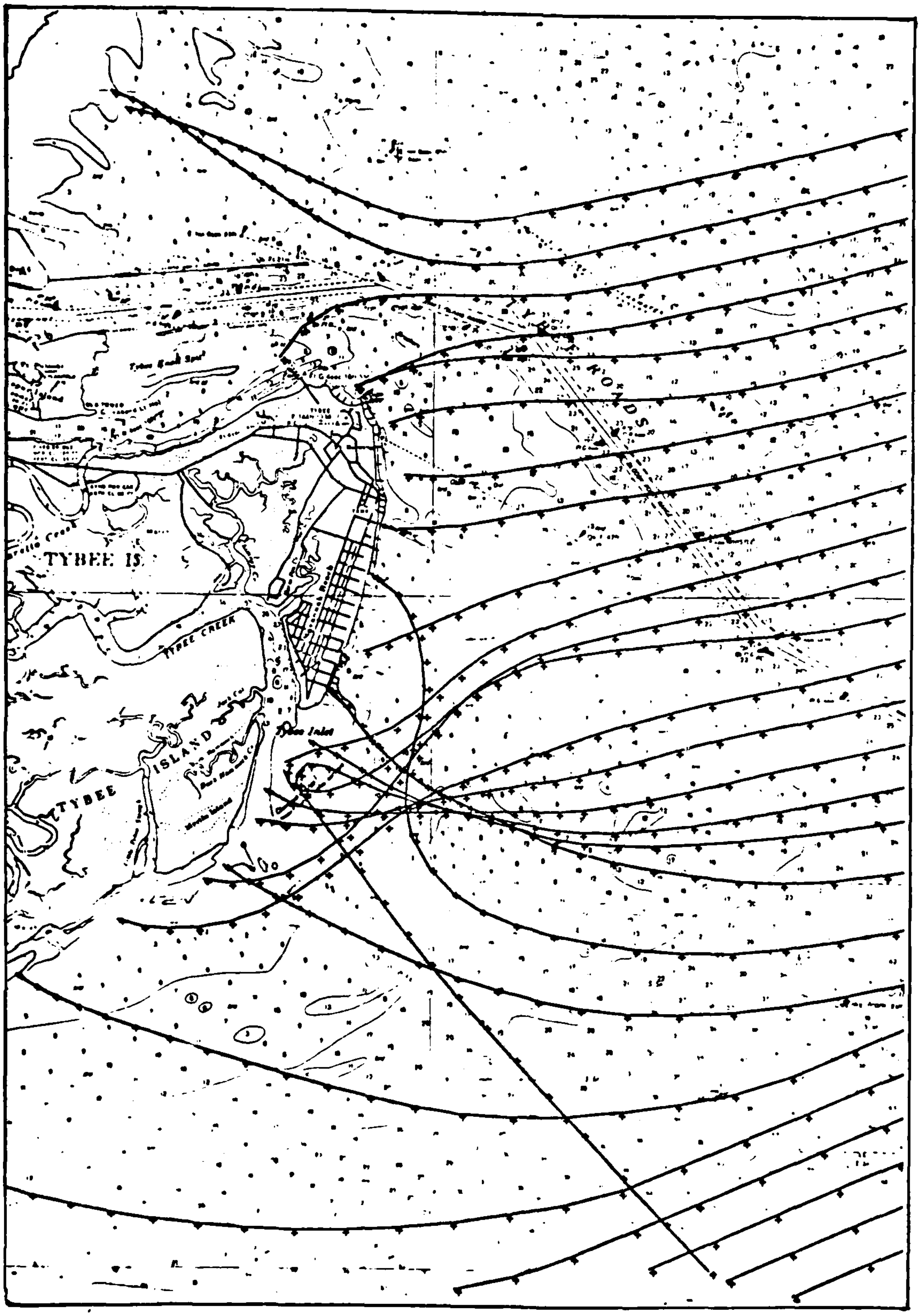

Figure D4. Refraction diagram with H = 5.5 ft, T = 6.5 sec, and $\alpha = 67°$

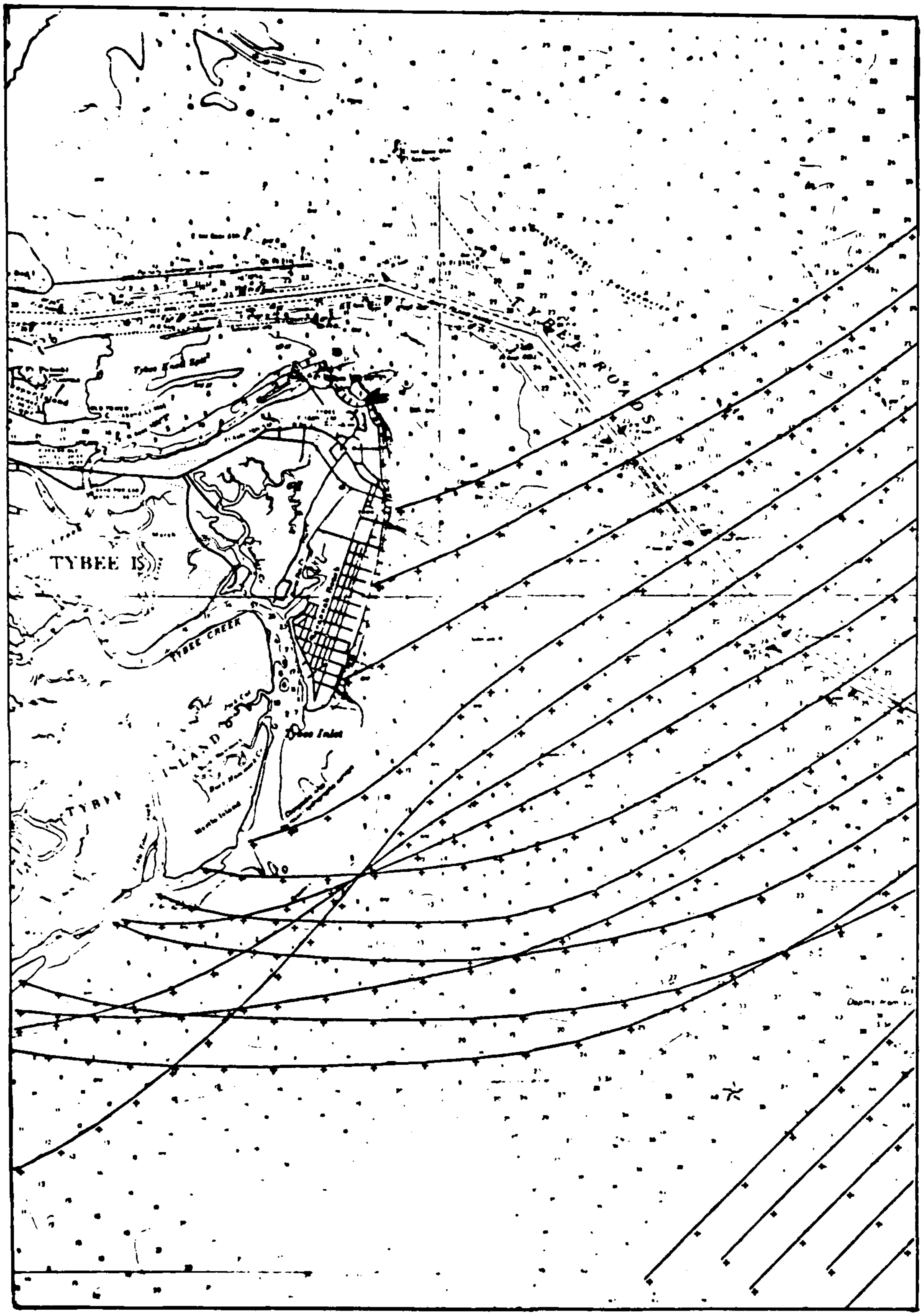

Figure D5. Refraction diagram with H = 5.5 ft,
T = 6.5 sec, and $\alpha = 45°$

APPENDIX E: PHOTOGRAPHS PERTAINING TO EROSION AT TYBEE ISLAND

Figure E1. North end of Tybee Island, 1935

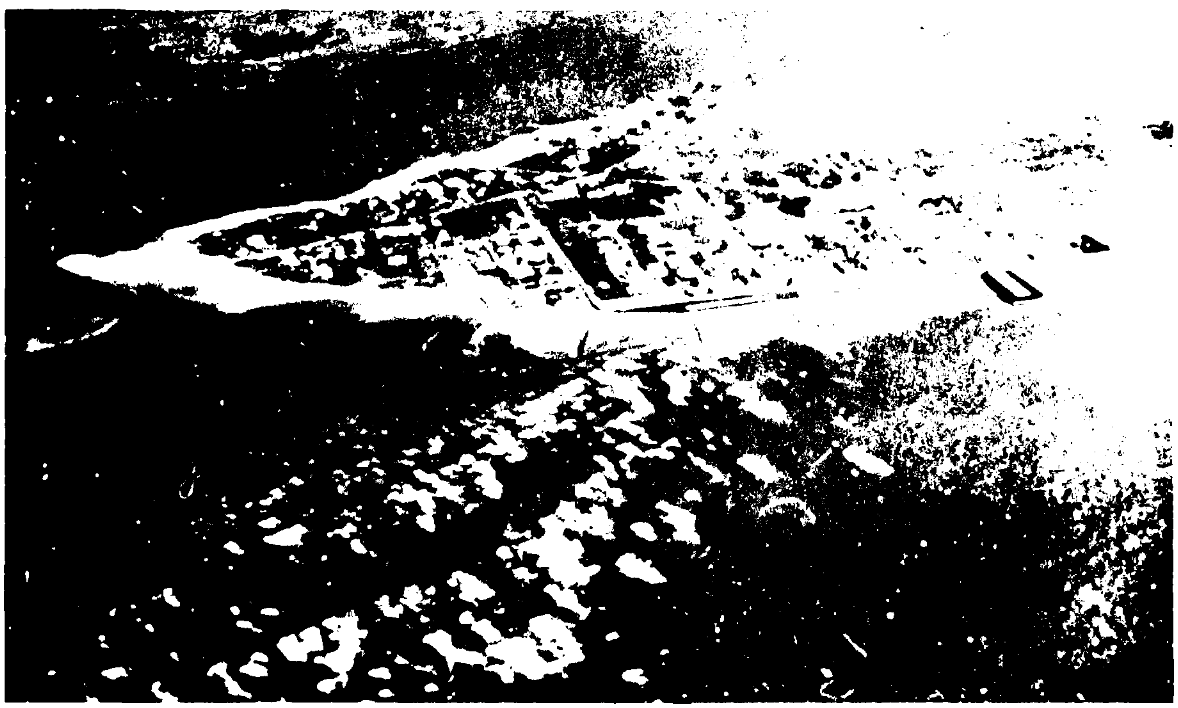

Figure E2. South end of Tybee Island, 1935

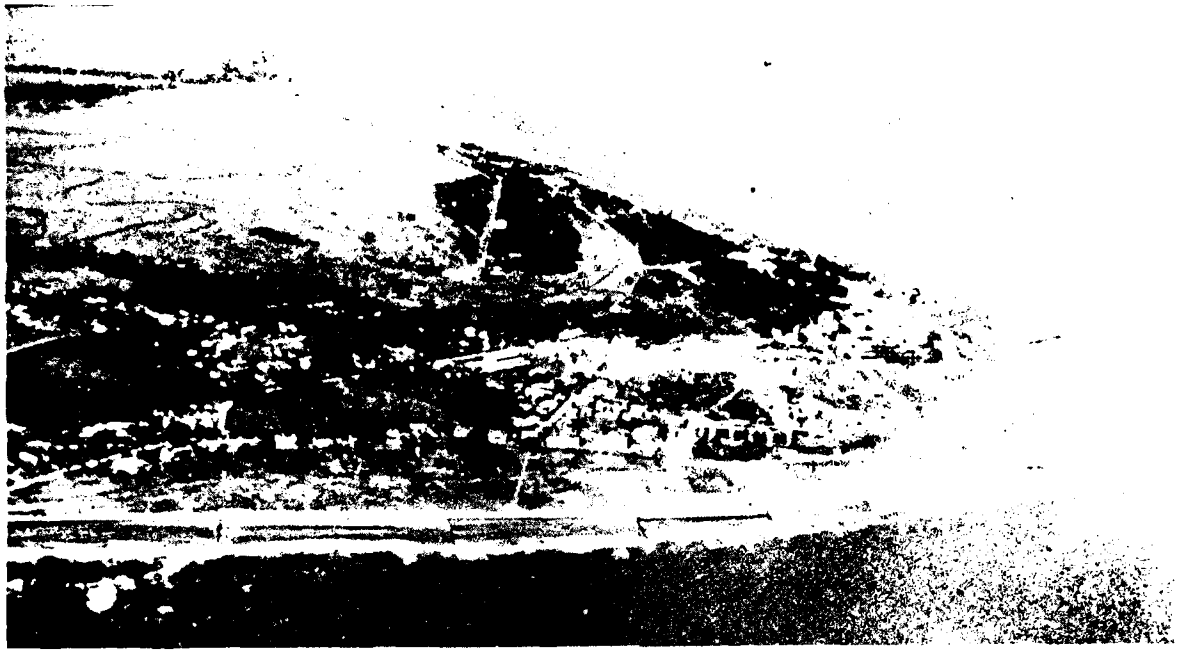

Figure E3. North end of Tybee Island, 1938

Figure E4. South end of Tybee Island, 1938

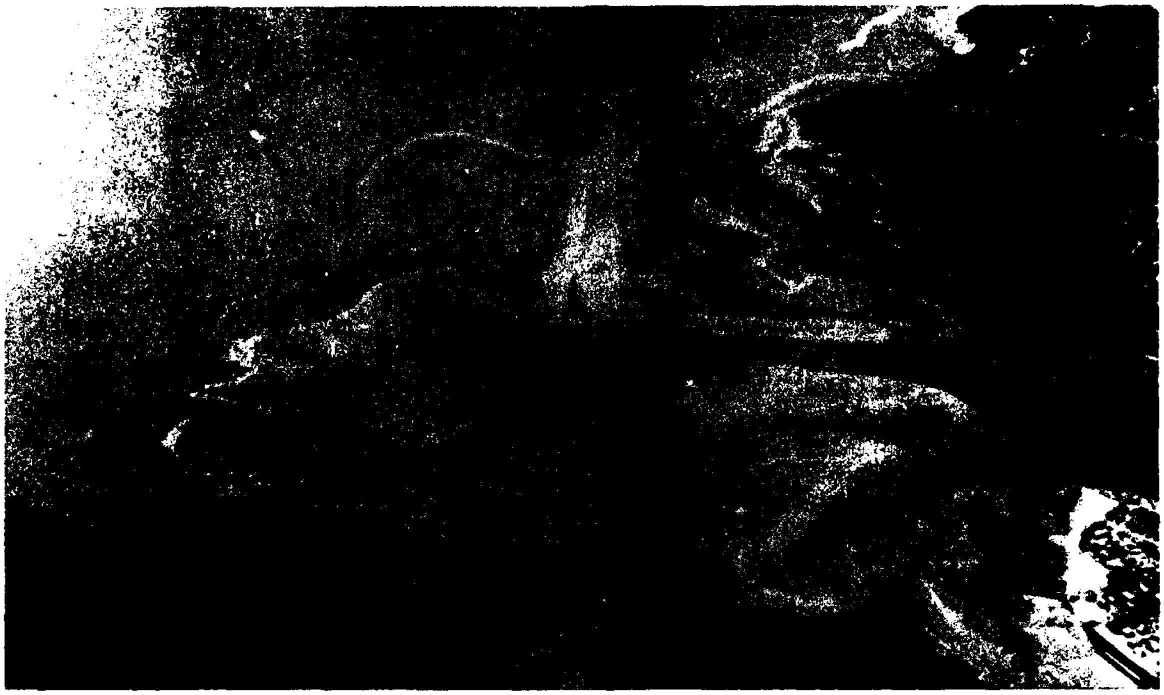

Figure E5. South end of Tybee Island, 1940

Figure E6. Aerial photo of Tybee Island, March 1965

Figure E7. Central portion of Tybee Island shore, 1966

Figure E8. Tybee Island, 1966

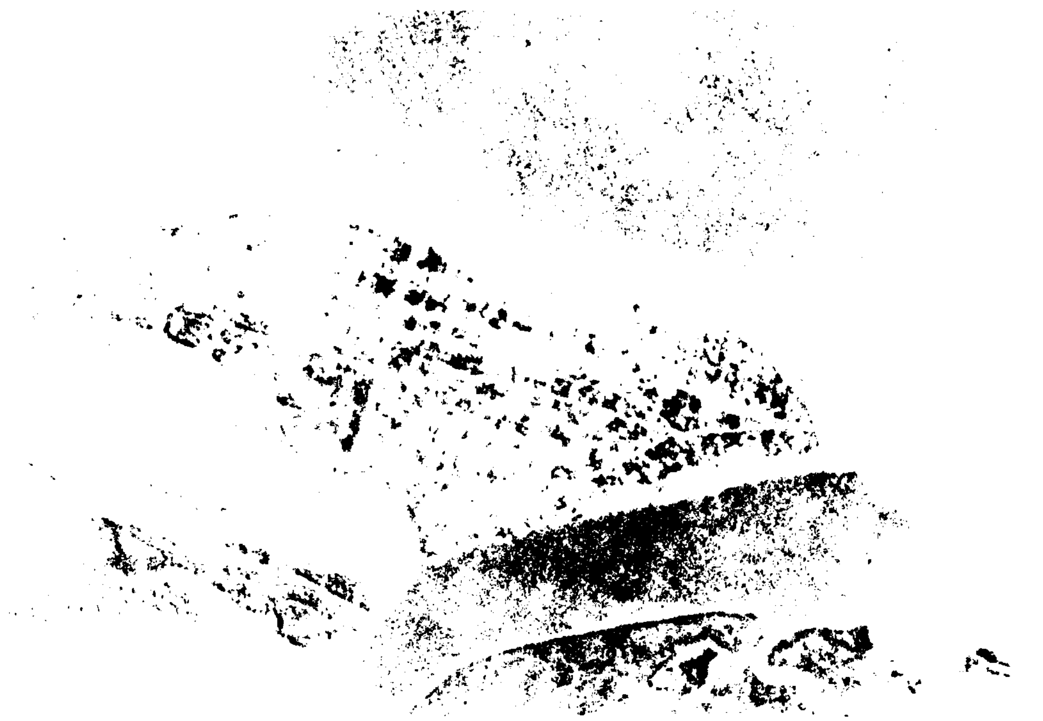

Figure E9. South end of Tybee Island, 1972

Figure E10. Northern tip of Tybee Island, 1972

Figure E11. Tybee Island beach after nourishment, 1976

Figure E12. South end of Tybee Island (approximately 1979)

Figure E13. South end of Tybee Island, 1978

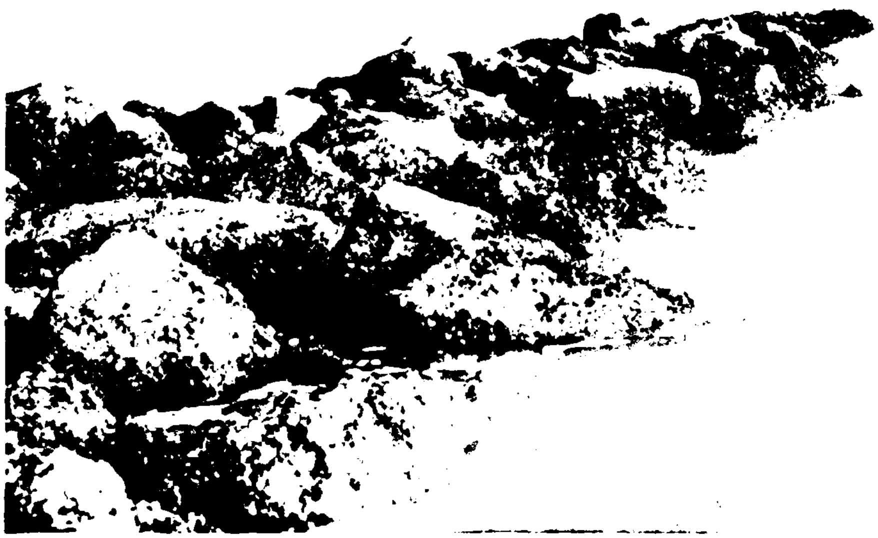

Figure E14. North terminal groin

Figure E15. South end of Tybee Island, aerial photo (approximately 1966)

Table E1

Aerial Photography of Chatham County, Ga.

Year	Scale	Area Coverage	Source
1952	1":330'	Complete	USDA-ASCS P. O. Box 9543 Savannah, Ga 31402 Ph: 912/232/4321, Ext. 202
1968	1":1320'	Complete	USDA-SCS P. O. Box 9381 Savannah, Ga 31402 Ph: 912/236-0761
1970	1":50,00	Complete	USDA-SCS P. O. Box 9381 Savannah, Ga 31402 Ph: 912/236-0761
1970	1":400' and	Complete	Metropolitan Planning Commission 2 Bay Street West Savannah, Ga 31402 Ph: 912/236-0761
1972	1":500'	Complete	Jack W. Berry Associates, Inc., P. O. Box 23 Morrow, Ga 30260 Ph: 404/361-6956 Ph: 404/361-4764

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